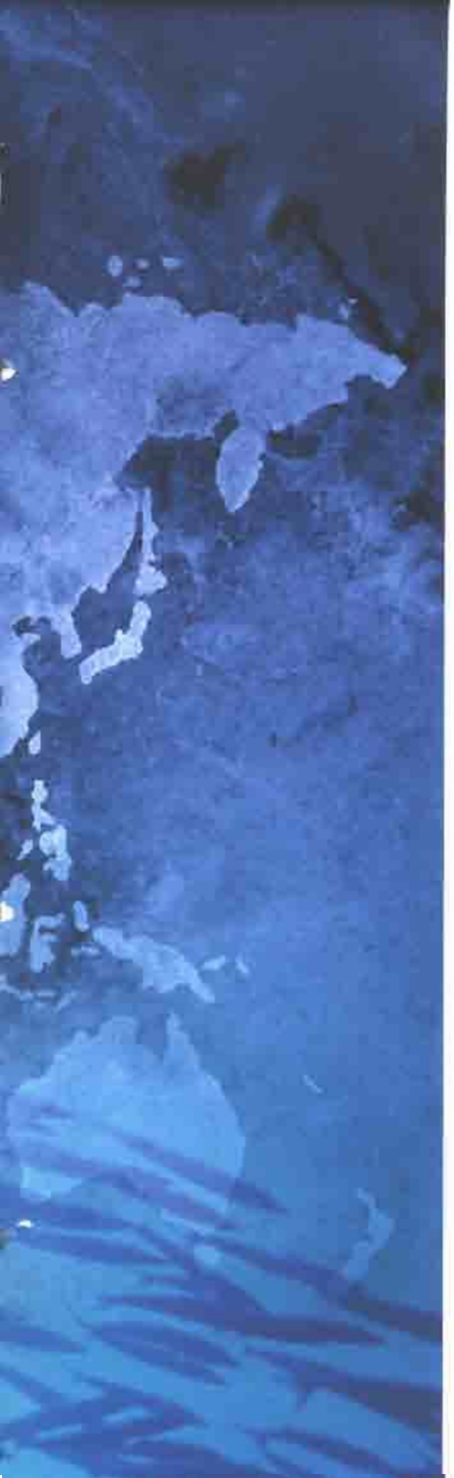
OCEANOGRAPHIC ATLAS OF KUWAIT'S WATERS

FAIZA YOUSEF AL-YAMANI, JAMES BISHOP,
ESSA RAMADHAN, MOHSEN AL-HUSAINI,
AND ABDUL NABI AL-GHADBAN


Oceanographic
ATLAS
KUWAIT'S
Waters



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OCEANOGRAPHIC ATLAS OF KUWAIT'S WATERS

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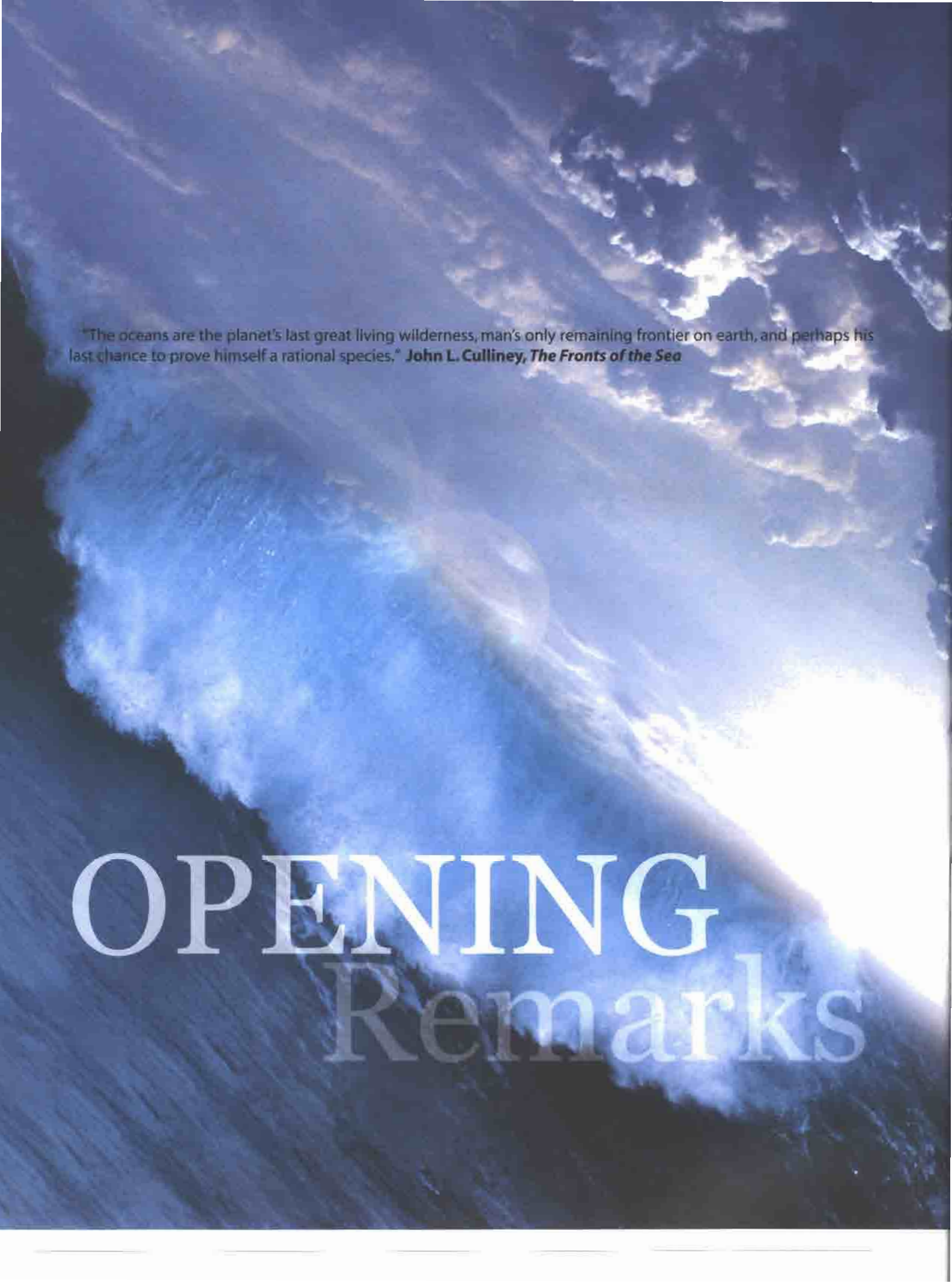
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"The oceans are the planet's last great living wilderness, man's only remaining frontier on earth, and perhaps his last chance to prove himself a rational species." **John L. Culliney, *The Fronts of the Sea***

OPENING Remarks



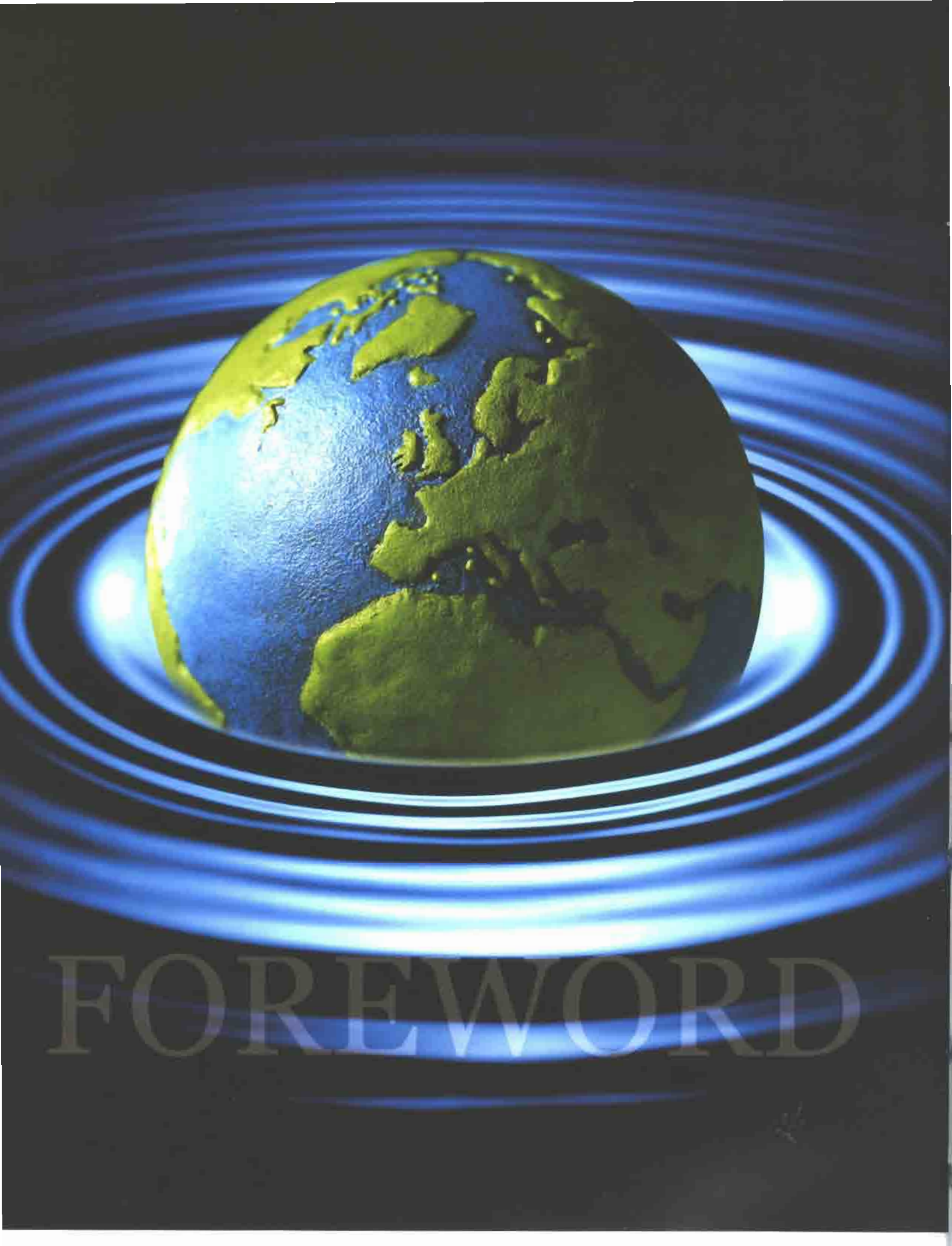
OPENING REMARKS

The ocean is our last frontier and one of profound contrasts. It surrounds us, yet we know relatively little about it. It is in constant motion, yet it is the earth's most stable environment. It can be a source of unimaginable productivity, and equally barren. Coral reefs easily rank among the world's richest and most colorful ecosystems, while deep sea environments are monotonous and depauperate of species. The sea regulates the earth's climate, and consequently, is responsible for droughts and floods. The abundance of water in liquid form sets the earth apart from all other known planets, and the sea is the primary reservoir of water. Without water, life as we know it, would not be possible. So the ocean, in a very real sense, serves as the planet's lifeblood.

The sea offers poetic inspiration, a source of food, a means of conveyance, a place of recreation, and a challenge to man's intellect. The reason that the ocean is the earth's final frontier is due to its size and the hostilities associated with probing its depths. Man has been exploiting the ocean's resources, like pearls and Tyrrhenian purple dye, for thousands of years. In the 1950s, we began exploiting the ocean's nonrenewable resources, such as oil and gas, initially in waters only 30 m in depth, but now to depths of hundreds of meters. The ocean is not immune to man's activities, however, as pollutants now contaminate the most remote seas and the greatest depths. Stocks of all major fisheries are either maximally exploited or over-exploited, and in 2003, stocks of all large carnivorous fishes were declared commercially endangered. The ocean's adaptive processes are only minimally understood, yet they may be the environmental buffer necessary to mitigate major changes in the atmosphere due to man's activities. To understand the ocean is to understand the planet, and satellite imagery, along with other technological advances, aids our ability to grasp this understanding.

Kuwait has a long and rich association with the Gulf, but scientific aspects of its territorial waters remain relatively unknown to the public. Much of the information on Kuwait's marine environment was accessible only to those involved with the research. The purpose of this atlas is to change that situation by summarizing much of the data gathered since 1977 and presenting them in a format friendly to user groups and interested individuals. Much of the information is presented in the form of diagrams, charts, graphs, photographs, and satellite images, which are intended to facilitate understanding Kuwait's marine processes within the context of the global environment.

The Authors



FOREWORD

FOREWORD

The relatively small geographic area of Kuwait's marine environment covers a very important zone of transition at the extreme NW corner of the Arabian Gulf. From north to south, Kuwait's coast covers a linear distance of 170 km of white sand beaches, rocky outcrops, extensive intertidal mudflats, and *Salicornia* marshes. The discharge of the Shatt Al-Arab River, the Gulf's major source of fresh water, reduces the salinity and increases turbidity in Kuwait's northern waters. The effects of the Shatt Al-Arab diminish rapidly, so that, in Kuwait's southern territorial waters, both salinity and water clarity are high. The maritime environment of Kuwait includes the Gulf's second largest island, Bubiyan Island, and three offshore islands with some of the world's most northern coral reefs. The outstanding feature of the local marine environment is Kuwait Bay.

A closely intertwined relationship has always existed between the land and the sea as the foundation of the Kuwaiti way of life. In commercial spheres, pearling and trading traditionally dominated Kuwait's maritime activities. Over the decades, as the economy began to rely on oil resources, the sea continued to play an important role as the primary avenue for transporting oil to international markets. Modern Kuwait is a nation also dependent on maritime resources in other ways as well. With very little naturally occurring fresh water, it is ironic that Kuwait has the world's highest per capita consumption of water. This contradiction is only possible because of distillation of the Gulf's waters, a process that has played a very important role in Kuwait's progressive development. Seawater is also used to cool power generation plants, which have also provided local energy resources for further development. Expansion of seafront and beach recreational facilities along Kuwait's coast has become increasingly important as the population increases. The famous seafood cuisine of Kuwait demands the ingredients of fresh fish and shrimp, one of the best naturally occurring, renewable resources the Gulf has to offer.

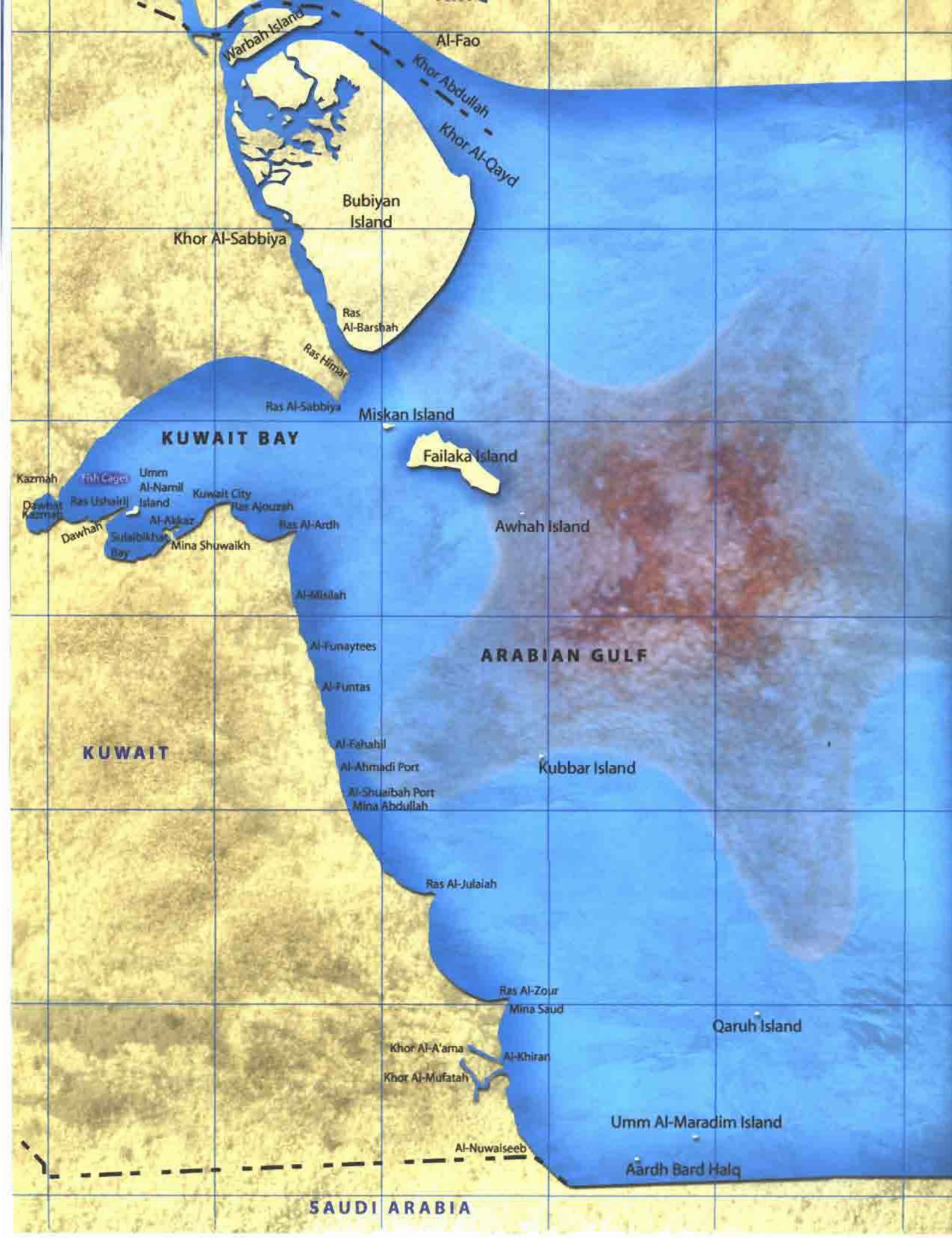
It is unfortunate that some of these seemingly beneficial uses of Kuwait's abundant sea resources have come in conflict with perpetuation coastal and marine resources. As in other modern nations, rapid development and industrialization over the past 40 years have often involved alterations and modifications to the marine environment that were not necessarily in Kuwait's strategic interests. Much of the highly productive intertidal area, which serves as valuable nursery habitat for many marine species of commercial importance, has been destroyed by reclamation projects. In Kuwait Bay alone, more than 10 square kilometers of intertidal habitat has been filled in for power generation stations, port development projects, recreation and other commercial concerns to meet the needs of a developing society, with over 60 % of its population under 24 years of age.

As an added strain to the marine and coastal environment, in February 1991, Kuwait experienced the worst act of eco-terrorism known in the history of mankind, with the deliberate discharge of an estimated six to eight million barrels of crude oil into its marine waters, along with the setting alight of 603 of the 1,073 land-based oil wells. Other ecological disasters have occurred or are occurring presently, with less notoriety than the oil pollution of the Gulf War, but with just as detrimental an influence. For example, the construction of 22 dams on the upper Tigris and Euphrates Rivers, 19 of which will be capable of power generation is of major concern. The result will be a much-reduced discharge of the Shatt Al-Arab and essentially no flooding. This flooding acts as a trigger in the timing of many species dependent on fresh water or reduced salinities for breeding. Since 1991, Iraq has drained nearly all the marshlands at the confluence of the Tigris-Euphrates Rivers. These marshes served as a major nursery ground for Kuwait's second most important shrimp species, *Metapenaeus affinis*. Additionally, one of Kuwait's most popular fish species, the Suboor *(Tenualosa ilisha)* requires rivers to spawn. It is highly predictable that the effect of the reduced discharge of the Shatt Al-Arab on the long-term population trends of these and other species dependent on reduced salinity in the waters of the Northern Gulf, such as Zobaidy *(Pampus argenteus)*, will be quite detrimental.

In view of such strains on its marine and coastal environment and valuable sea resource, Kuwait's greatest challenge in finding solutions to these dilemmas lies ahead in the new millennium. With these challenges in mind, the authors of the *Oceanographic Atlas of Kuwait's Waters*, provide valuable information on how Kuwait's marine environment fits into the larger perspective of the Gulf and the world's oceans. This atlas was created to serve as a source of specific information about Kuwait's waters as well as providing a general introduction to the fascinating field of marine science. This atlas should serve to guide decision-makers and developers in the sustainable use of what has been, and, hopefully, will continue to be Kuwait's most valuable resource, the Gulf waters.

We would like to thank the Environment Public Authority for jointly funding the Atlas project which was carried out by Kuwait Institute for Scientific Research.

Dr. Abdul Hadi Al-Otaibi
Director General
Kuwait Institute for Scientific Research


Warbah Island
Al-Fao
Khor Abdullah
Khor Al-Qayd
Bubiyan Island
Khor Al-Sabbiya
Ras Al-Barshah
Ras Himar
Ras Al-Sabbiya
Miskan Island
KUWAIT BAY
Failaka Island
Kazmah
Fish Cages
Umm Al-Namil Island
Kuwait City
Dawtiat Kazmah
Ras Ushairij
Ras Ajouzah
Al-Akkaz
Ras Al-Ardh
Dawhah
Sirlaibikhat Bay
Mina Shuwaikh
Awhah Island
Al-Misilah
Al-Funaytees
ARABIAN GULF
Al-Puntas
KUWAIT
Al-Fahahil
Al-Ahmadi Port
Kubbar Island
Al-Shuaibah Port
Mina Abdullah
Ras Al-Julaiah
Ras Al-Zour
Mina Saud
Qaruh Island
Khor Al-A'ama
Al-Khiran
Khor Al-Mufatah
Umm Al-Maradim Island
Al-Nuwaiseeb
Aardh Bard Halq
SAUDI ARABIA

PRELUDE

The Oceanography Atlas is a pioneer work for Kuwait and the Arabian Gulf Region. Its approach to present the information specific to Kuwait within a regional or global context will provide readers with a perspective not previously available in a single reference. For the first time, many environmental data not readily available are presented in an easily understood format. This Atlas will serve as a valuable reference for professionals, students, and interested laymen alike. Since the Gulf War, the Kuwait public has become more environmentally conscious, and recent events such as the fish kill in 2001 have reinforced the public's interests. Social, economic, and environmental concerns are interdependent, and this Atlas should help people understand and grasp some of the complicated environmental issues. We hope that scientists at the Kuwait Institute for Scientific Research (KISR) will continue their excellent work in data gathering, interpretation, and publication, so that the public has more information to draw upon when involved in the complex decisions confronting today's society.

The valuable contributions by all the authors, reviewers and editors are gratefully acknowledged. We express our deep gratitude for their enormous commitment and involvement in the writing of this book.

Dr. Mohammad Abdul Rahman Al-Sarawi
Chairman and Director General
Environment Public Authority (EPA)





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We express our gratitude to the Kuwait Institute for Scientific Research and the Environment Public Authority for supporting and funding the production and publication of this Atlas.



BACKGROUND

Oceanographic surveys of the Arabian Gulf have been carried out since the 1900s, and results have been reported by several investigators, e.g., Schott (1918), Blegvad (1944), Emery (1956), Al-Yamani (1989), Al-Yamani et al. (1993), and ROPME (1993a, 1993b). The northwestern waters of the Gulf, especially off Kuwait, have been investigated by the scientists of the Meteor expedition (Anon., 1966-1977), Hendy (1970), Kuronuma (1974), Basson et al. (1977), Brewer et al. (1978), Brewer and Dyrssen (1985), Anderlini (1979), Anderlini et al. (1978, 1982), Jacob et al. (1979, 1981), Dames and Moore (1983), Michel et al. (1986), Lee et al. (1983, 1985a, 1985b, 1990), Jones and Clayton (1983), Al-Yamani et al. (1993, 1997a, 1997b), Al-Rifaie and Al-Yamani (1996), Ismail and Al-Yamani (1996), Subba Rao and Al-Yamani (2000), Al-Yamani and Khan (2001), Prusova et al., (2001), and others.

Several governmental agencies in Kuwait conduct surveys of the marine environment. The Environment Public Authority (EPA) samples 13 reference stations in Kuwait's inshore and coastal waters each month. Measured variables include seawater temperature, transparency, pH, salinity, dissolved oxygen concentration, oxygen saturation, chlorophyll concentration, suspended solids, concentrations of ammonium, nitrite, nitrate, phosphate and silicate, densities of plankton and benthos. Other reference stations are monitored routinely for pollutants, bacterial counts (indicator of sewage pollution), and for harmful algal blooms. Results of these surveys are published in monthly reports. An important project concerning the rehabilitation of Kuwait Bay is presently being conducted by EPA.

Scientists at the Kuwait Institute for Scientific Research (KISR) conduct mission-oriented research. Many of KISR's projects concern oceanography, fisheries and marine biology with a focus on food-chain dynamics and ecosystem-based studies. Two important projects, the Masterplan of Bubiyan Island and the Impacts of Shatt Al-Arab diversion and the draining of the Mesopotamian marshes on Kuwait's ecosystem, are being carried out by KISR. Scientists at Kuwait University (KU) are currently involved in several marine projects: Kuwait's marine turtles, energy flow in the intertidal ecosystem in Sulaibikhat Bay, and the biology of the silver pomfret (*Pampus argenteus*). Kuwait's Government has funded a major study of Kuwait Bay (1982) and is currently (2003) funding a Masterplan of Bubiyan Island. The Kuwait Foundation for the Advancement



of Sciences (KFAS) funded a very important project, Development of a Strategic Plan for Kuwait's Marine Environment, which integrated scientific knowledge, and social aspects of Kuwait's marine habitat (Al-Yamani et al., 2000). The Regional Organization for the Protection of the Marine Environment (ROPME) sponsors selected oceanographic surveys within the Arabian Gulf region, Gulf of Oman and part of the Arabian Sea.

The oceanographic data collected by the different organizations are fragmented, scattered, reported in different formats, and have not been summarized or presented in a comprehensive, uniform manner. There are three atlas-type documents of Kuwait; one on shoreline types and resources, with emphasis on the sensitivity of the coastal environment (Al-Sarawi et al. 1985), one on satellite remote sensing applications in Kuwait (Kwarteng and Al-Ajmi, 1997), and most recently, one on the terrestrial and nearshore environments, also utilizing satellite imageries (El-Baz and Al-Sarawi, 2000). The initial atlas (Al-Sarawi et al., 1985) addressed the need for a sensitivity guide with respect to coastal environments and associated wildlife in the event of a major oil spill. This atlas of shoreline types provides descriptions of Kuwait's coast by profiling 25 selected coastal stations, identifying 10 environmental sensitivity indices (ESI), and covering the entire coast in 11 maps with ESIs and biological features. The shoreline types included manmade (concrete walls, harbors), socioeconomic components (marinas, power generation plants, recreational areas), and natural features (beach-rock outcrops, fine-sand beaches, intertidal mudflats, etc.). Al-Sarawi et al. (1985) chose three biological components in their sensitivity atlas: coastel birds, fishes, and reptiles. The birds and fishes were subdivided into selected groups, and reptiles, consisted of marine turtles only. Succinct discussions of Kuwait's geology, sediments, climate, oceanography, and fisheries are also included. Although some aspects of this atlas are now outdated, most of the information remains very useful and is presented in a manner not available elsewhere.

The Satellite Remote Sensing Applications atlas (Kwarteng and Al-Ajmi, 1997) demonstrated the usefulness of satellites to assess aspects of Kuwait's environment. Examples of remote sensing as it applies to Kuwait's geomorphology, urbanization, agriculture, rangeland, coast, and marine habitat are covered in this atlas. More specifically, this atlas includes, images of the impact of the 1991 oil fires on Kuwait's desert surface, the presence and extent of subkahs, areas of overgrazed desert, surface mining of gravel, the spread of urbanization from Kuwait City, and the distribution of turbid waters in the northern Gulf.

The most comprehensive atlas of Kuwait's environment is provided by El-Baz and Al-Sarawi (2000). Their *Atlas of the State of Kuwait from Satellite Images* provides much more information than implied by the title alone. This atlas contains a good background on Kuwait's environmental setting, including geography, topography, history, archaeology, climate pattern, geology, seismic activity, mineral resources, oil and water resources, coastal features, coral reefs, and fisheries. None of these topics is dealt with in depth. A separate section concerns the environmental effects of the Gulf War. The atlas divides Kuwait into fives regions or provinces: northern, western, southern, coastal and islands, and discusses prominent features of each. Kuwait City is included in the Coastal Province. The aerial photographs of the islands, except Bubiyan, are definitely the most complete available as each of Kuwait's nine islands are covered.

Usually, every new marine atlas summarizes the information available up to the time of publication. Because observations in Kuwait's waters were too sparse and inadequate, except for inshore areas, previous atlases could not address the marine environment in detail. The accumulation of recent data allows considerable improvement in mapping the oceanographic parameters. We have compiled most of the results and information from several KISR multi-disciplinary oceanographic studies, especially those conducted by the Mariculture and Fisheries Department, into a single integrated and comprehensive document. The results presented here represent the first oceanographic atlas of Kuwait's waters.

The urgency to compile oceanographic data and produce an atlas are prompted by rapid and irreversible changes occurring in Kuwait's waters, especially those to the north. Without proper documentation and understanding of the natural characteristics of our marine environment, man-made or anomalous changes will be difficult, if not impossible, to assess.

"The sea is many things: it is a chemistry, a biology, a geology, a physics, a realm of endeavor and learning, in fact, for all of the natural sciences and technological disciplines of man." **Seabrook Hull, *The Bountiful Sea*.**



INTRODUCTION TO OCEANOGRAPHY

What is Oceanography ?

Oceanography is the scientific study and exploration of the oceans and seas and all their aspects. This includes the ocean bottom, the interaction of the sea and atmosphere, the internal and external forces affecting seawater composition and motion, the internal forces affecting the ocean bottom, and the living organisms and their behavior. The organic and inorganic components of the oceans interact and affect each other. Thus, oceanography is not a single discipline per se, but rather a combination of basic sciences amalgamated with technology that integrates, synthesizes, and blends many types of knowledge and encompasses many sub-disciplines. Because the study of oceanography often examines in detail all the different disciplines of science, it is often described as being an interdisciplinary science, or a scientific field covering all the disciplines of science as they apply to the oceans. There are several important applications of marine science in the fields of medicinal science (Table 1), biotechnology and bioengineering.

Table 1. Pharmaceuticals from the Ocean

Sea Life	Derived Compounds and Pharmaceutical(s)	Some Actual and Possible Uses Under Investigation
A species of seaweed	Calcium alginate	Stops human bleeding
A species of seaweed	Sulfated lamarin	Prevents blood clotting
Irish moss	Carrageenin	Treatment of gastric ulcers and production of collagen
Songes (various species, e.g., *Tethya crypta, Crytpotethya crypta*)	D-arabinosyl cytosine (Ara-C) Ara-A	Inhibits tumor growth (antitumor) Anticancer Antiviral
Various species of sponges (e.g., *Luffariella variables* and others)	Various compounds (e.g., Agosterol A, Jasplakinolide, Naamidine A, and Manolide)	Lowering blood pressure, improving muscle tone of the heart, combating virus disease and some forms of cancer, anti-inflammatory/psoriasis
Stonefish (family Synanceiidae), the world's most venomous fish	Various compounds	Lowering blood pressure
Sea cucumber	Various substances	Treatment of tumors
Quahaug clam	Various substances	Treatment of tumors
Sea whip (*Plexaura homomalla*)-Gorgonian	Substances similar to the prostaglandins, anti-inflammatory drug	Source of hormones that are essential to basic biochemical processes, anti-inflammation
Bioluminescent jellyfish (*Aequora victoria*)	Aequorin	Bioluminescent calcium indicator, an effective reagent for measuring very small changes in calcium concentrations in humans; such changes often are precursors of cellular and bone diseases
	Green Fluorescent Protein (GFP)	Reporter gene
Octopus	Serotonin	Histamine releaser

Table 1(continued). Pharmaceuticals from the Ocean

Sea Life	Derived Compounds and Pharmaceutical(s)	Some Actual and Possible Uses Under Investigation
Sea Anemone	Serotonin	Histamine releaser
Octopus (*Eledone moschata*)	Eledoisin (ELED)	A peptide (tachykinin)-serves as a model for synthesizing new families of drugs in the laboratory
Marine Algae, bacteria, and fungus, some larger invertebrates (e.g., the sea pork/ascidian, *Amaroucium stellatum*)	Antimicrobial agents (e.g., Cephalosporin C)	Antibiotics
Red algae	Phycoerythrin	Conjugated antibodies used in ELISAs and flow cytometry
Pufferfish, sunfish, and porcupine fish	Tetrodotoxin	Treatment of cancer
Phytoplankton (e.g., dinoflagellates)	Paralytic shellfish poisons, saxitoxin, Okadaic acid	Chemical model for anesthetics and drugs for heart and nervous disorders
Starfish and sea cucumbers	Various compounds	Heart-stimulating and nerve-blocking drugs

Main Oceanographic Disciplines

The study of the oceans embraces, in particular, four basic sciences: physics, geology, chemistry and biology. Other disciplines include meteorology, satellite oceanography, ocean engineering, marine archaeology, anthropology, and marine policy (including law, economics, or political science), which deals with environmental problems, conservation and management of marine resources.

- Physical oceanography is the study of waves, tides, currents and circulation; the ocean-atmosphere relationship that influences weather and climate; and the transmission of light and sound in the oceans.

- Geological oceanography (marine geology, geophysics and geochemistry) is the study of processes of shoreline formation, of the structure of the sea floor and how the sea floor has changed through time; the creation of sea floor features and plate tectonics; and the history of sediments deposited on it (their formation, transport, and deposition). The earth's surface is divided into nine large plates. These plates rest on top of the molten rock below the surface of the earth, which could be up to 60 miles deep. These plates are in constant motion, and depending on their location, they may be "spreading apart" or "colliding". Continental drift, seafloor spreading, mountain chains, earthquakes, and volcanoes are all manifestations of tectonic plate activity. Geological oceanography deals also with the earth magnetism, seismic activity, carbonate studies (including coral reefs), and bioturbation by benthic organisms as well as bathymetric surveying.

- Chemical oceanography is the study of the chemical composition and properties of seawater; air-sea chemical interactions; sediment-sea interactions; cyclic processes; how to extract certain chemicals from seawater; and the effects of pollutants. One area of focus is on the origin and breakdown of organic material in marine sediments. Chemical oceanographers seek understanding of the extent to which the environment may be changed by both natural and man-made phenomena operating on a variety of scales.

- Biological oceanography is the study of marine life forms and their relationships to one another; adaptations to the marine environment, and developing ecologically sound methods of harvesting seafood as in fisheries science. The structure of marine ecosystems and the energy flow within the marine food web under various natural and man-made environmental factors are central questions of biological oceanography.

The above disciplines are so interdependent, that scientists often use the term "physico-chemical" and "biogeochemical" processes when referring to their interactions. For example, algae absorb dissolved inorganic nutrients from the marine environment and with the aid of sunlight transform these nutrients into organic matter. This organic matter is either consumed by a higher trophic level or recycled back into the environment by decomposition. In this manner, living components of the oceans influence "non-conservative chemical components". Some elements in seawater, such as sodium or chlorine, are essentially unchanged by the biogeochemical cycle and are referred to as being "conservative". Organisms living in the substratum turn over the sediment (bioturbation), hence, recycling buried nutrients back into the water column, and organisms feeding on suspended particles by filtering processes (suspension feeding) cause the deposition of particles (organic and inorganic). Thus, the oceans' biological components intimately affect chemical and geological processes, and vice versa.

Physical oceanography and meteorology, the study of the earth's atmosphere, are two very closely related and interdependent disciplines. Because of the similarities of air and water, the general equations describing the motions and behavior of these two fluid media are essentially the same. The main differences are that water is only slightly compressible, and the coefficient of friction is relatively large. Air, on the other hand, is highly compressible, and the coefficient of friction is relatively small. Wind, generated by differential heating of the earth's surfaces, in conjunction with the earth's rotation, causes waves and currents, which result in oceans' major circulation patterns. Energy, stored as heat in seawater, determines the world's climate, and causes major climatic events such as cyclones (also known as typhoons or hurricanes). It is through the use of oceanographic and meteorological satellites that TV stations are able to provide us with summaries of weather patterns on global and continental scales. Accurate "ground truth" data from all over the world over a long period of time are required to explain global weather patterns and to develop predictive models.

Air-sea interactions drive the oceans' deep currents through density gradients created by evaporation and cooling as surface currents move toward the poles. Other currents move along the equatorial regions. Because the Pacific is the earth's largest ocean, it is the main driving force for much of the earth's climate, and changes in the Pacific's equatorial currents have global consequences. Two general climatological conditions exist, popularly known in Spanish as *La Niña*, "the little girl," and *El Niño*, "the little boy". La Niña's effects on global weather are roughly opposite to those of El Niño. As a result, El Niño, La Niña and Southern Oscillation are often referred to collectively as El Niño/Southern Oscillation (ENSO), a cycle that oscillates year-to-year between warm, cold and neutral states in the tropical Pacific (Fig. 1). The Southern Oscillation, is a multi-annual (3 to 7 years) fluctuation in the rise and fall of surface atmospheric pressure over the southern part of the Pacific, between the Australian–East Asian region and the eastern tropical Pacific. Mann and Lazier (1996, p. 283) stated, "In this oscillation the usual pressure gradient from the region of high atmospheric pressure in the southeast Pacific Ocean to the region of low pressure in the area of Indonesia becomes higher or lower than average. A lower-than-average pressure gradient favors El Niño conditions, while the higher-than-average situation has been called La Niña".

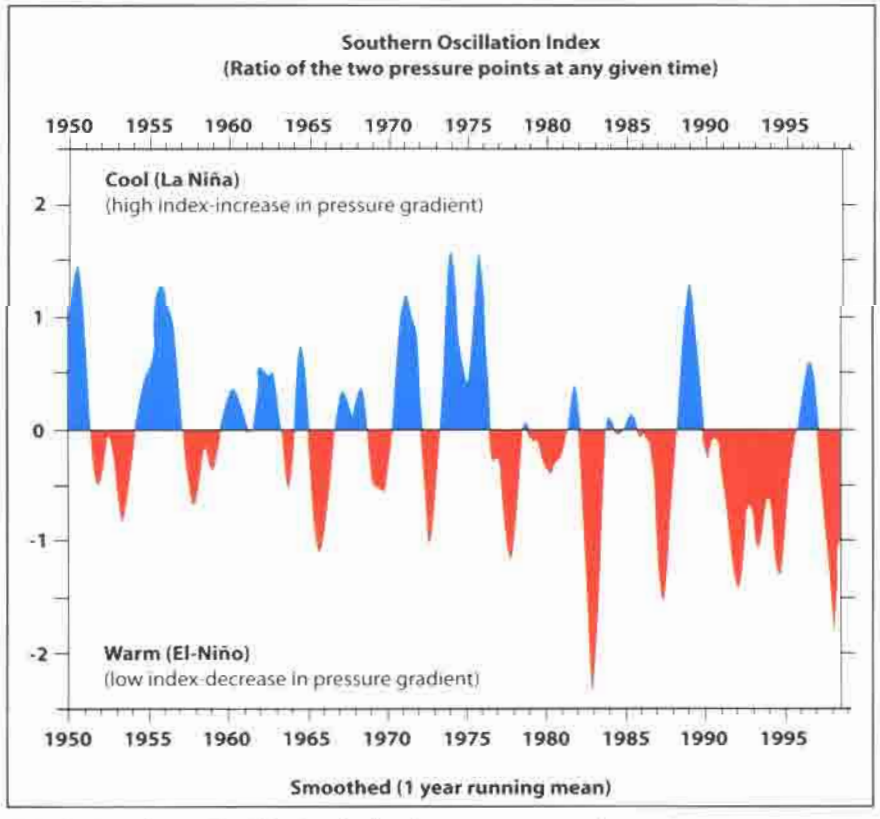


Fig. 1. Southern Oscillation Index for pressure gradients between Australia and Tahiti. Source: Deen, P.; L. DuBois; and A. Jrujillo, 1999. Laboratory and Field Exercises in Oceanography, 4th Edition, Paladin House Publishers.

El Niño

El Niño is a warming of the tropical Pacific that occurs roughly every three to seven years and lasts for 12–18 months. It is dynamically linked to the Southern Oscillation. During El Niño, the trade winds weaken along the equator as atmospheric pressure rises in the western Pacific and falls in the eastern Pacific (Fig. 2). Weakened trade winds allow warm surface water, normally confined to the western Pacific, to migrate eastward. As these waters migrate eastward during El Niño, so does the heavy rainfall. Wind-driven upwelling, a process that brings nutrient rich cold water

to the surface along the equator and along the west coasts of North and South America, is greatly reduced, causing sea surface temperatures to rise, and the rain pattern to shift from the western Pacific to the eastern Pacific. Droughts occur in Indonesia and Australia, allowing outbreaks of major fires and the destruction of thousands of hectares of tropical forests. Even weather patterns in Africa are affected. Depending on the severity and duration of the trade wind change, the consequences can be catastrophic. El Niño can also have a positive influence on weather, such as bringing milder winters to North America and suppressing Atlantic hurricane formation. Upwelled waters are rich in nutrients that support biological productivity, so that reduced upwelling adversely affects marine ecosystems and economically valuable fish stocks. Therefore, strong El Niño years upset the ecological conditions along large areas of the South American coast, with effects on the fisheries. A particularly striking example of the socio-economic consequences of El Niño was the collapse of the Peruvian anchoveta fishery following the 1972–1973 El Niño (Glantz, 2001). Peru was the most productive fishing nation in the world in the late 1960s and early 1970s, and the annual catch of anchoveta was over 10 million metric tons, one fifth of the world's total. Intense fishing pressure and extraordinarily high mortality rates during the 1972–1973 El Niño caused the fishery to crash. For at least 10 years following the 1972–1973 El Niño, anchoveta landings ranged between only 1/10–1/3 the catch of 1970.

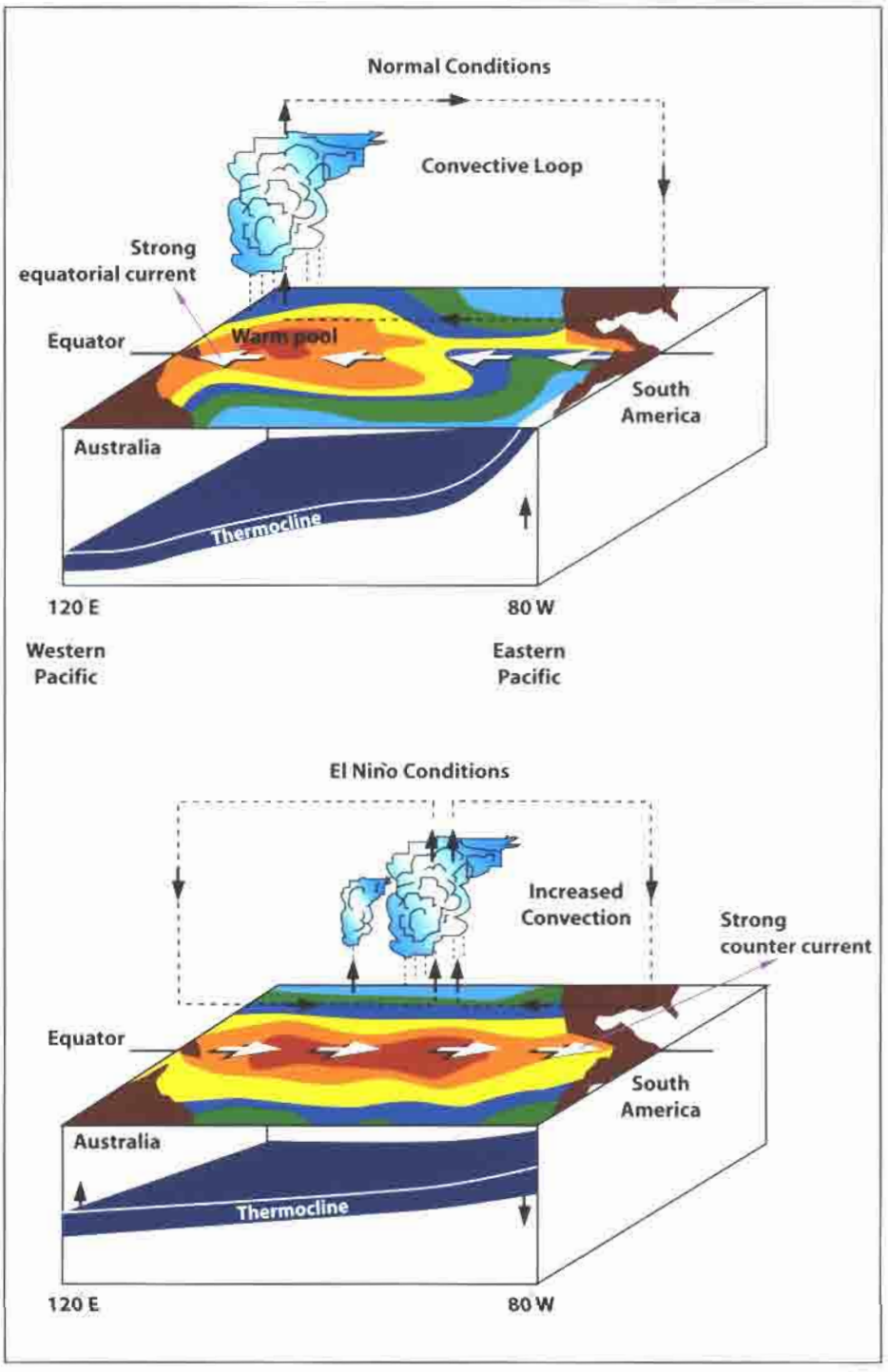


Fig. 2. Normal and El-Niño conditions. Source: www.pmel.noaa.gov/tao.elniño

Upwelling

In general, upwelling (Fig. 3) refers to the upward movement of nutrient-rich deeper water into the sunlit upper layers (photic zone) of the water column. Upwelling results from persistent winds displacing surface waters away from the coast. Narrow coastal and equatorial upwelling zones account for much of the biological productivity in the world's oceans. These biologically productive areas with high densities of plankton (minute phytoplankton and zooplankton organisms) are at the base of the marine food chain in these regions, and all higher organisms depend directly or indirectly on them as a food source. Upwelling ecosystems are rich in species diversity and abundance, including many types of phytoplankton, zooplankton, shellfish, crustaceans, fish, marine mammals, and sea birds. Many of these fish and shellfish species such as tuna, anchoveta, sardines, squid, and shrimp are valuable commercially. Major upwelling areas with large fish populations and fisheries are found along the west coasts of Mauritania, Namibia, Peru and the southern coast of Oman and Yemen on the Arabian Sea.

La Niña

La Niña is a climatological phenomenon analogous to El Niño, but with opposite tendencies and effects in

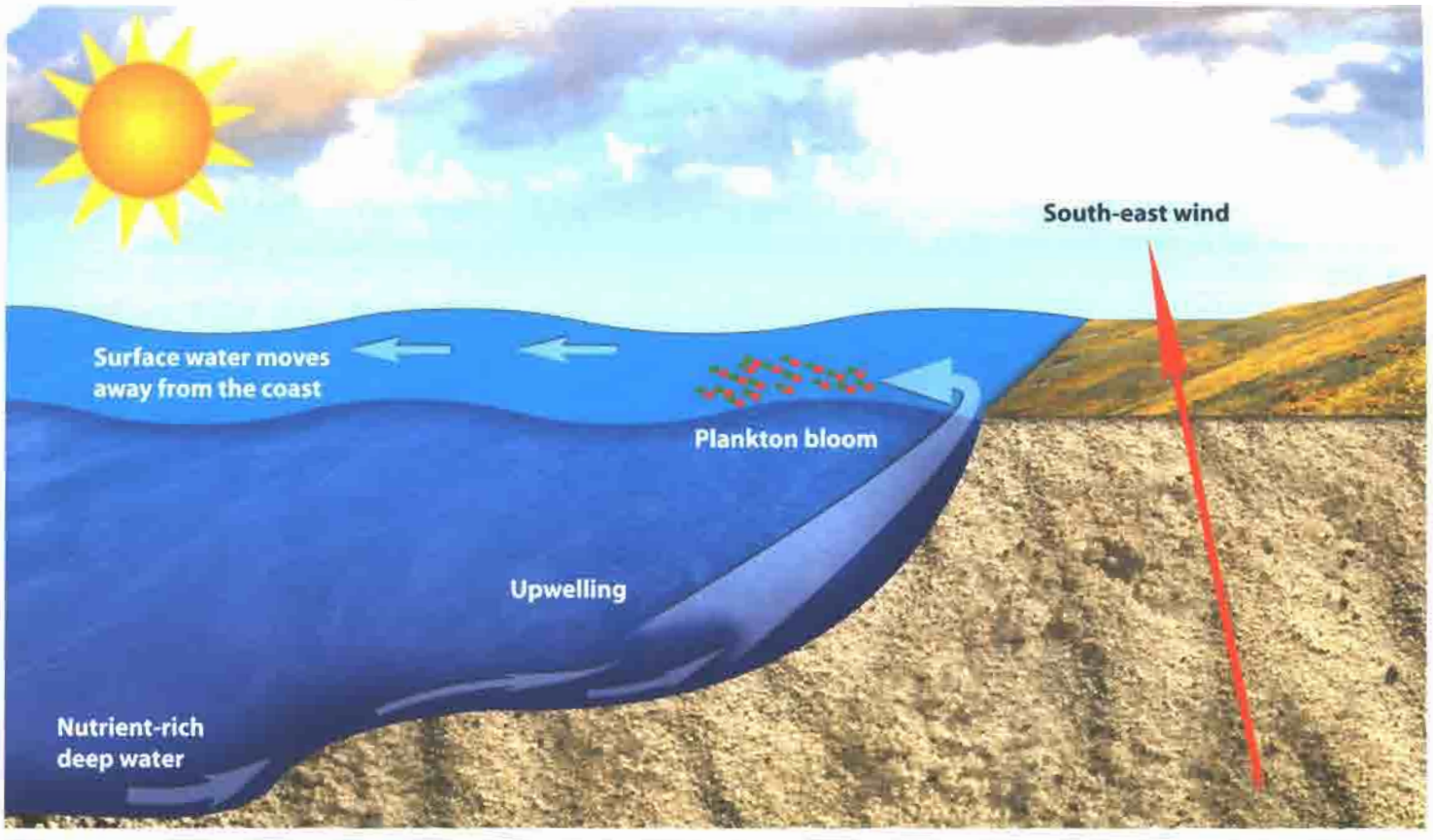


Fig. 3. The upwelling event.

the tropical Pacific Ocean and on global weather (Fig. 4). It is the cold phase of the ENSO cycle. Like El Niño, La Niña typically lasts 12–18 months, and affects tropical storm frequency, intensity, and geographical distribution through changes in sea surface temperature and atmospheric circulation.

La Niña is characterized by stronger than normal trade winds and colder than normal tropical Pacific sea surface temperatures. It is also characterized by unusually high surface atmospheric pressure in the eastern tropical Pacific and low surface pressure in the western tropical Pacific in association with the Southern Oscillation. Therefore, easterly trade winds blow west cross the tropical Pacific, causing surface waters to pile up in the western Pacific. The sea's surface in Indonesia becomes about 0.5 m higher and seawater temperature becomes 8 °C warmer than it is in the east Pacific, along the west coast of South America. This causes low rainfall along the coasts of Peru and Ecuador, while in the western Pacific rainfall is high. Other examples of La Niña weather impacts include an increased probability of unusually rainy conditions in southern Africa and northeastern Brazil, and in the monsoon regions of India, Indonesia and Northern Australia. La Niña is often linked to drier than normal conditions over equatorial East Africa, southern Brazil and Uruguay. In the eastern North Pacific, more frequent cold polar fronts push

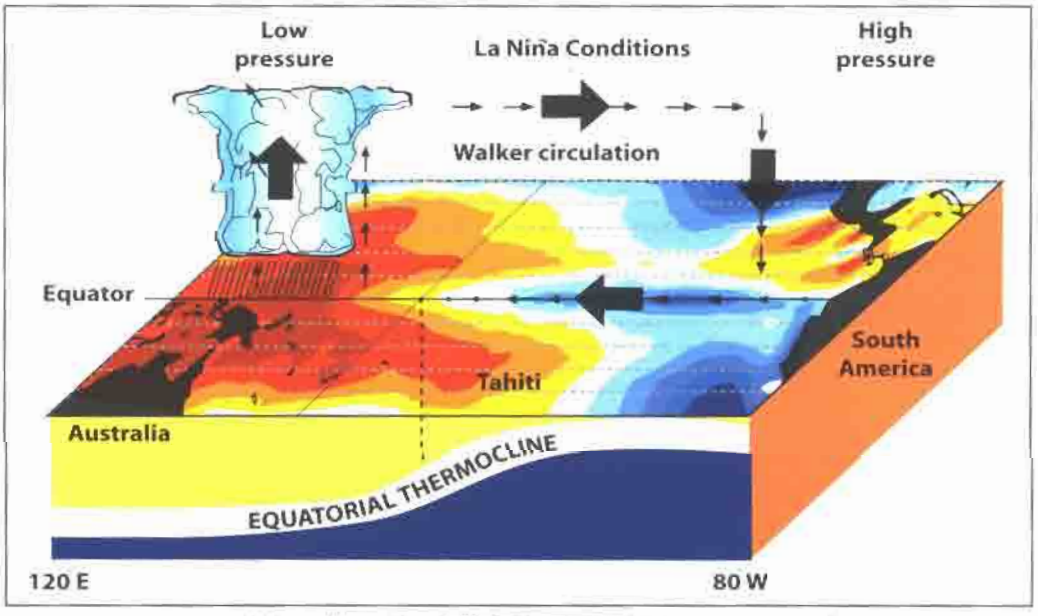


Fig. 4. La Niña condition. Note the shift in the location of low atmospheric pressure reflecting an increase in the strength of the Walker circulation, and the shallowing of the thermocline in the eastern Pacific. Source: Deen, P.; L. DuBois; and A. Jrujillo, 1999. Laboratory and Field Exercises in Oceanography, 4th Edition, Paladin House Publishers.

over western North America. These changes in atmospheric pressure patterns and circulation result in winters that tend to be colder and stormier than normal over Alaska, western and central Canada, and the northern US.

Although the above situation is most frequently referred to as *La Niña*, it is also and more accurately known as *El Viejo* or "the old man" due to the westerly winds pushing surface waters along western South America offshore, bringing cold, nutrient-rich waters from depth to replace them. This phenomenon is most evident off the coast of Ecuador and Peru, creating one of the world's most productive fisheries. The upwelled nutrients and cool-water temperatures provide ideal conditions for phytoplankton production, which in turn support the world's richest anchovy fishery. Thus, winds can affect the ocean's nutrient concentrations, which in turn determine productivity and the resulting food chain leading to fisheries.

Importance of Oceans and Seas

The oceans and seas receive energy from the sun, winds and tides, and distribute that energy around the globe. In addition, oceans and seas transform chemical matter from the ocean and marine basins and continents, and cycle that matter through living organisms and sediments.

Importance of the Arabian Gulf. The Arabian Gulf has influenced our life in many ways for a long period of time, both directly and indirectly. The Gulf is of strategic, social and economic importance.

The Arabian Gulf waters serve as a:

- source of food for human consumption (fish, crustaceans, mollusks);
- source of feed for livestock;
- source of petroleum and minerals (such as salt);
- source of beautiful and valuable Gulf pearls;
- source of drinking water through desalination;
- source of cooling water for industry and power generation;
- source of sands and gravels;
- highway for navigation, transportation and commerce;
- place for recreation and tourism (swimming, water-skiing, jet-skiing, sport fishing, boating, scuba diving, sea travel); and
- place for waste disposal.

The Oceans of the World

All the oceans of the planet constitute one vast global ocean called the World Ocean, which is considered as a global biosphere.

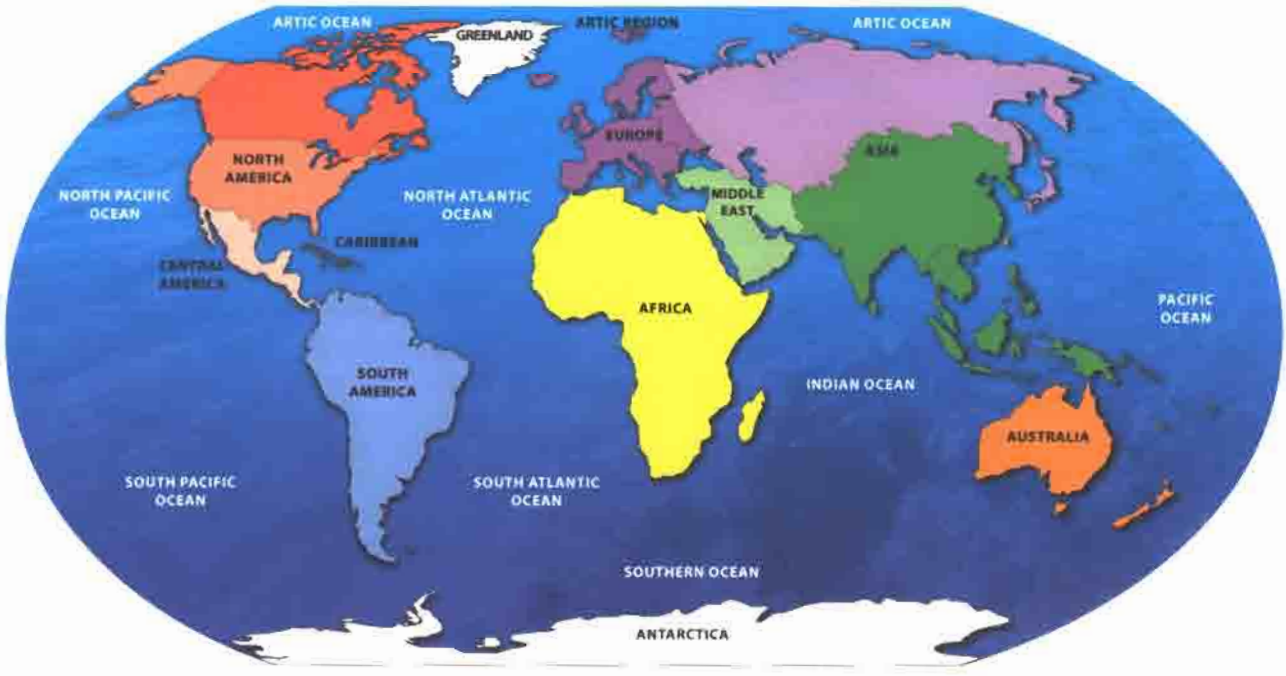


Fig. 5. The five oceans of the world.

Table 2. Area, Mean Depth and Deepest Spot of the World's Five Oceans.

Ocean	Area		Mean Depth		Deepest Depth		Deepest Location
	km^2	mi^2	m	ft	m	ft	
Pacific	166.3×10^6	64.2×10^6	4,638	15,215	11,022	36,163	Mariana Trench
Atlantic	86.5×10^6	33.4×10^6	3,926	12,881	8,605	28,231	Puerto Rico Trench
Indian	73.6×10^6	28.4×10^6	3,890	12,760	7,450	24,442	Java Trench
Southern	20.3×10^6	7.8×10^6	ca. 4,496	ca. 14,750	7,235	23,736	South Sandwich Trench
Arctic	13.2×10^6	5.1×10^6	1,205	3,953	5,450	17,881	Eurasia Basin

There are five major oceans in the world (Fig. 5, Table 2): the Atlantic, Indian, Pacific, the Arctic (located in the north pole region) and the Southern, which extends from the shores of Antarctica northward to about 40°S latitude.
The oceans are not uniformly distributed on the face of the earth:

- About two thirds of the earth's land area is found in the Northern Hemisphere.
- The oceans encompass over 80% of the Southern Hemisphere.

The major oceans are further subdivided into smaller water bodies called seas, gulfs, or bays.

Ocean Statistics 1. Total Area of the oceans comprises 71% of earth's surface area (361 million km^2). The oceans contain 97% of the earth's water, whereas less than 1% is fresh water, and 2-3% is contained in glaciers and ice caps. Mean ocean depth is 3,795 m. The deepest spot is the Challenger Deep in the Mariana Trench; about 11,000 m (11 km or 36,163 ft) deep. Mount Everest is only 8,848 m (8.8 km) high. Ocean volume is estimated to be 1.4 billion km^3 of water. The world's coastlines are about 504,000 km long, whereas the earth's circumference at the equator is only 40,165 km (24,902 miles).

Ocean Statistics 2. The Pacific is by far the largest ocean, covering an area of 166 million square kilometers; an area equivalent to the Indian and Atlantic Oceans combined. The Pacific also has the greatest average depth (4,638 m) and absolute deepest spot at 11,022 m. This depth below sea level is 25% greater than the world's highest mountain (Mount Everest, 8,848 m) above sea level. The Atlantic and Indian Oceans rank second and third in area at 86.5 and 73.6 million square kilometers, respectively. The Arctic is the smallest of the world's oceans (13.2 million square kilometers) and the shallowest, averaging only 1,205 m in depth.

Seven Seas. The term refers to the Arctic Ocean, the Southern Ocean, the Indian Ocean, the North and South Atlantic Ocean and the North and South Pacific Ocean.

Inter-relationship of the Ocean and the Atmosphere

The atmosphere affects the oceans, and, in turn, is influenced by them. The action of winds blowing over the ocean surface creates waves and currents. The surface circulation of the oceans is closely tied to the prevailing wind circulation. In turn, the oceans act upon the atmosphere. Oceans influence and modify the world's climate and weather systems. The atmosphere obtains about half of its energy for circulation from the condensation of evaporated ocean water.

The oceans have higher thermal capacity than that of the atmosphere, therefore, the seasonal fluctuation of ocean temperatures is much less than that of the atmospheric temperatures. Also, because of the higher thermal capacity of ocean water, when air blows over the ocean, the air temperature is more affected by the water temperature than vice versa.

In general, maritime climates are less variable than climates of the interior regions of the continents.

Wind Direction and Velocity.

- Wind, refers to the flow of air relative to the earth's surface.
- Wind direction refers to the direction from which the wind blows, e.g., a wind coming from the northeast (NE) is a northeast wind blowing toward the southwest (SW) (compass directions: N, NE, E, SE, S, SW, W, NW).
- A wind vane determines wind direction.
- Wind velocity is measured by means of an anemometer or radar. Wind speed is reported in knots (nautical miles per hour), mph (miles per hour), or m/s (meters per second): 1 knot = 1.15 mph = 0.5 m/s
- The highest documented wind speed is 318 mile/h (516 km/h), measured during a 1999 tornado in the U.S. State of Oklahoma.

Winds and Ocean Currents.

- Ocean surface currents are driven by the wind.
- The overall transport of water in the surface layer is at an angle to the direction in which the wind blows.
- The direction of movement of the surface water is to the right (of the wind direction) in the Northern Hemisphere and to the left in the Southern Hemisphere. This direction is a result of the Coriolis Force, which is a deflecting force, due to the earth's rotation.
- Wind-generated ocean waves continue to travel after the wind stops.

Tides

Tides are caused by the rotation of the earth in the presence of the gravitational pull of the moon and sun (celestial bodies). Tides refer to the alternating rise and fall in sea level with respect to the land, occurring on a regular or cyclic bases. These changes are caused by the gravitational attraction of the moon and, to a lesser extent, of the sun on the earth. Gravitational force is directly proportional to the masses of the bodies causing the force, but inversely proportional to the cube of the distance between the bodies. Because of its close proximity, the moon is about 2.17 times more influential on the earth's tides than is the sun, even though the latter is far more massive.

The highest tides occur when the sun and moon are in a line with the earth. Coastal locations experience the regular and predictable occurrence of low and high tides each day.

The range of the tides is the difference in sea level between high and low tides. Tidal ranges vary throughout the month, depending on opposing gravitational forces of the moon and sun. They also vary around the world, and average about 2 to 3 m (6 to 10 ft). The world's highest tides occur in the Bay of Fundy in eastern Canada, with a tidal range reaching 16 m (53 ft). High or low tides occur about 40 minutes later each day. The Mediterranean, Baltic and Caribbean Seas are relatively tideless.

Types of Tides.

- Tides can be diurnal, semidiurnal or mixed.
- A location with semidiurnal tides experiences two high tides and two low tides each day.
- A location with diurnal tides experiences one high tide and one low tide each day.
- Mixed tides means that there are two high tides and two low tides, but one of the two highs (or one of the two lows) is appreciably higher than the other or the interval between successive tides is unequal. Mixed tides can also refer to a location in which diurnal tides occur for part of the year and semidiurnal tides occur for the other part of the year.
- As the tides change, currents must flow to redistribute the seawater. Near the coast, the direction of the current changes every 6 1/4 h from toward the shore (flood current) to away from the shore (ebb current).
- Because tidal motion is measured over time, the tide is essentially a big wave with a 24 (or 12) h period. It is generated by gravitational, not wind, forces. Tides are larger near the equator than they are near the poles.

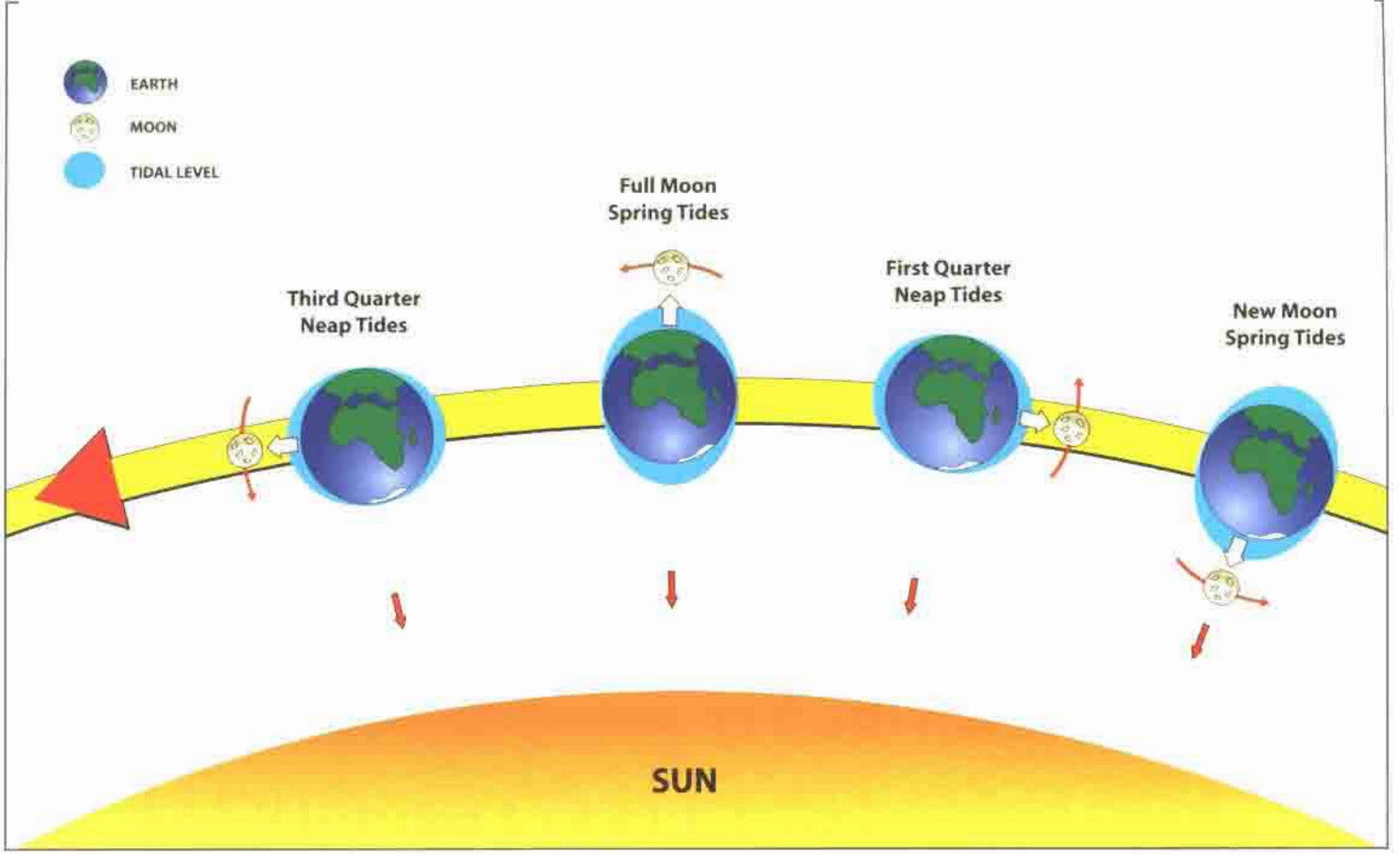


Fig. 6. A diagram showing spring and neap tides.

Tides (Fig. 6) are classified as follows:

Spring Tides. Spring tides, characterized by the maximum range during the month, are formed when the moon, the earth and the sun are aligned. During these tides, there will be very high tides and very low tides. Spring tides occur during the full moon, when the earth is between the moon and the sun, and during the new moon, when the moon is between the earth and the sun. Because of its restricted connection to the open ocean, and its shallowness (bathymetry) causing frictional forces, spring tides in the Arabian Gulf often experience a lag effect (of a few days) with the moon phases.

Neap Tides. When the moon, the earth and sun are at right angles to each other, neap tides result. Neap tides are characterized by the minimum tidal range during the month. Neap tides occur during the moon's first and last quarters, when the moon, earth and sun form a right angle.

Importance of Tides.

* Knowledge of tidal timings, heights and tidal currents has a wide range of practical applications:
- High and low tides have an important effect on the shore's wildlife.
- Tides disperse coastal pollutants. Without tides, coastal waters would be more sensitive to sewage or effluent disposal and runoff from the land.
- Tides create currents that mix the water and nutrients, transport plankton to sessile filter feeders, such as oysters and sponges, and transport and mix coastal sediments.

* Knowledge of tidal regimes is extremely important for different activities, such as the following:
- navigation within estuaries, bays and harbors;
- construction of bridges, docks, breakwaters and deep-water channels; and
- provision of information that is indispensable to fishing, boating and water sport activities.

Tides in Kuwait's Waters. Along Kuwait's coast, semidiurnal tides occur, with four different tides per day: two highs and two lows. Starting from the lowest tide of the day, the tides progress from a low-low (L-L) to low-high (L-H), then to a high-low (H-L), and finally to high-high (H-H), the highest tide of the day. These heights are given in meters from the average lowest tide, thus L-L is often close to zero meters or a fraction above. The mean tidal amplitude in Kuwait Bay is about 2 m, but tides can vary from 3.5 to nearly 4 m, depending predominately on the lunar phase. Occasionally, Kuwait's tides are negative, so they are even lower than the average lowest tide. The greatest tidal range in Kuwait Bay during the year 2003 occurred on 22 January (Fig. 7a) when 4.45 m separated the lowest (-0.85 m) and highest tides (3.60 m). The -0.8 5 m tide ranked that year's lowest. The highest tide of 2003, however, occurred about six months later on 16 June when the HH reached 3.91 m (Fig. 7b). The corresponding LL tide that day was - 0.17 m, for an overall difference of 4.08 m. Low spring tides tend to occur during the day in winter and during the night in summer, sparing the intertidal fauna the environmental extremes. Due in part to the Gulf's narrow ellipsoid shape and very restricted connection to the open ocean, Gulf tides experience a seiche (oscillation or sloshing) effect, which amplifies tidal effects at the northern end. This results in tides at Bubiyan and Fao Peninsula being more extreme than those in Kuwait Bay and Kuwait's coast to the south. Therefore, the Gulf's greatest tides occur at the north end of Bubiyan Island, the coast of Iraq, and the adjacent part of Iran. During spring tides, the currents reach 0.5 to 0.6 m/s, with a maximum of 1 m/s at the entrance of Kuwait Bay.

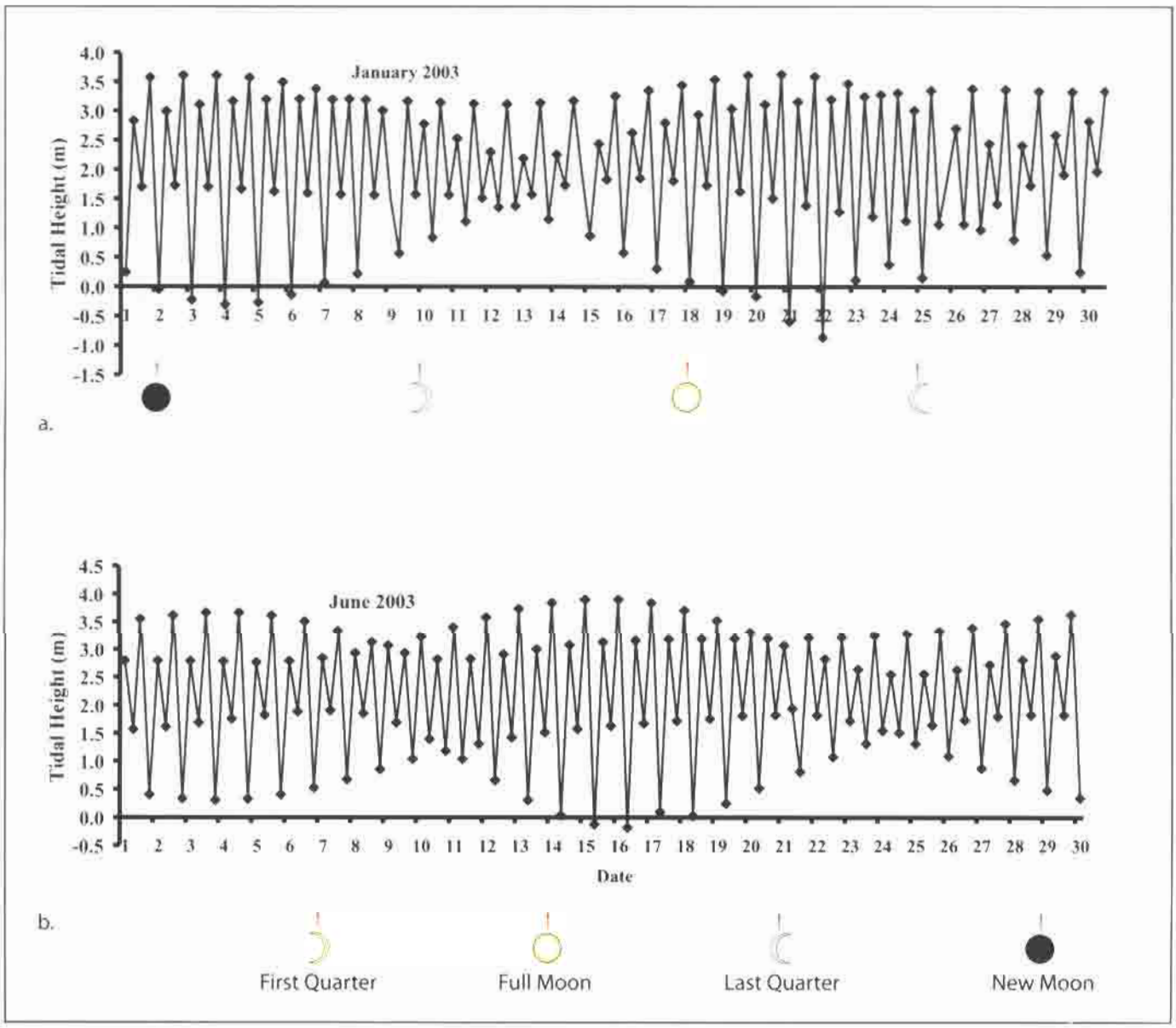


Fig. 7. Daily tidal heights for Shuwaikh Port (in Kuwait Bay) in a. January 2003, and b. June 2003. Data obtained from Kuwait's Ministry of Communication Tide Table.

Seawater Temperature. Seawater temperature determines many of the physical properties of the seawater, together with its salinity. It is measured in situ (at the actual spot or location in the natural environment) at different depths with instruments such as:

- the bathythermograph (instrument that records the variation of temperature with the depth-thermal structure of the water column);
- XBT (expendable bathythermograph-measures temperature electrically and sends its signal to the ship via a thin electric wire that breaks when the instrument has reached its maximum depth);
- the CTD (conductivity, temperature, and depth) recorder; or
- reversing thermometers.

In oceanography, temperature is measured in degrees Celcius (°C) (Fig. 8).

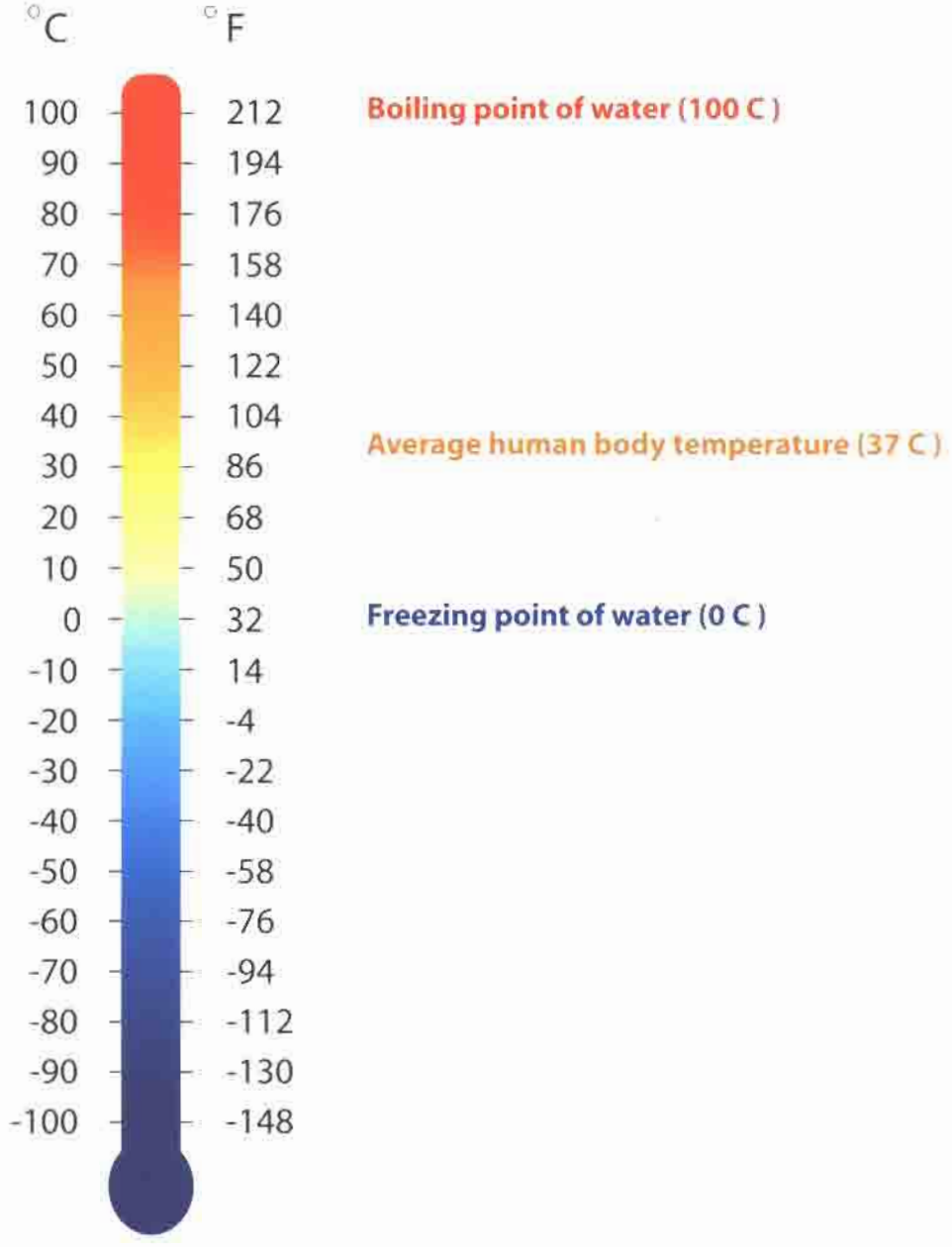


Fig. 8. Temperature scale in degrees Celcius (°C) and in degrees Fahrenheit (°F).

Isotherm. Seawater temperature of the water column at a specific location could be of the same temperature from the surface to the bottom layer. The line connecting points of equal temperature is called an isotherm (iso for "same"; therm for "temperature"). An isotherm can be represented horizontally at the sea surface or vertically as a profile with depth (Fig. 9).

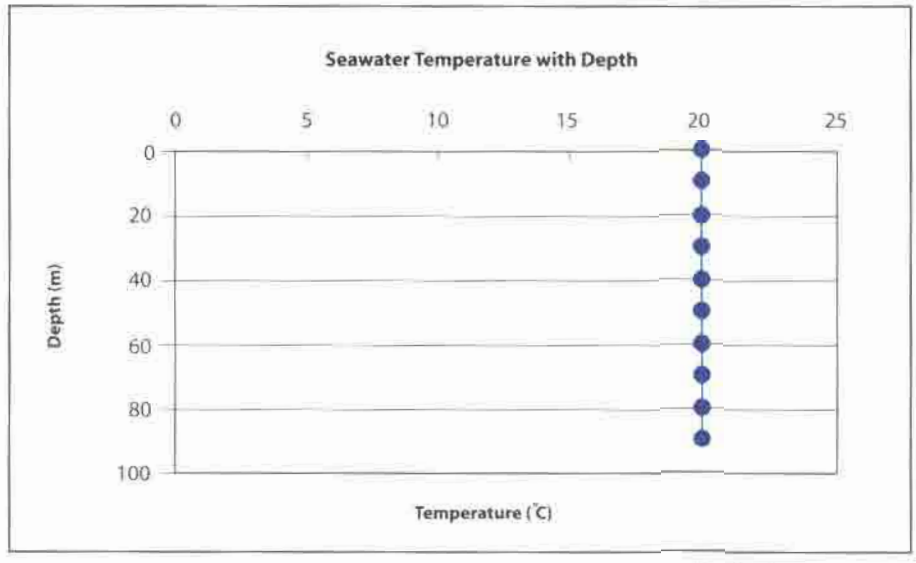


Fig. 9. Vertical profile of temperature in the water column displaying an isotherm; no thermocline present.

Thermocline. On the other hand, seawater temperature usually varies with depth. If there is a distinct difference between the temperature of the surface water and deep water, there will be a region in the water column where there is a strong temperature gradient, i.e., where the temperature decreases suddenly with depth. The region where this strong temperature gradient exists is called the thermocline (Fig. 10).

The average temperature of the oceans is 3.9°C (39°F), a few degrees above the freezing point of pure water (0 °C).

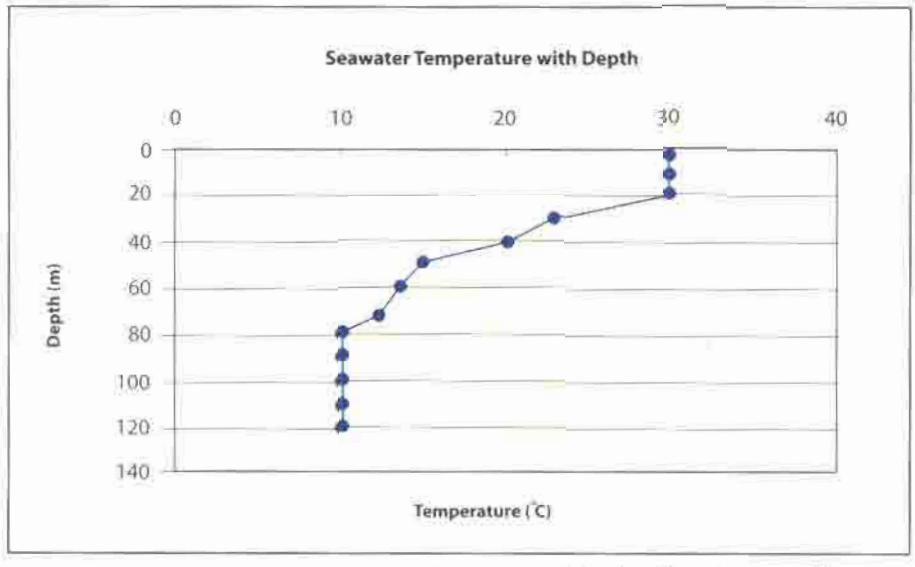


Fig. 10. Vertical profile of temperature versus depth with a thermocline from 20 to 80 m.

Temperature and the oceans.

- The deep water in the world's ocean is cold. Its source is the polar regions.
- Seawater becomes denser as it becomes colder.
- The freezing point of seawater depends on its salt content.
- The freezing point for seawater is -1.9 °C.
- A seawater temperature of 400 °C (700 °F) has been measured at one hydrothermal vent in the ocean. Hydrothermal vents refer to hot water that flows in an upwelling manner from cracks on the ocean floor.
- Temperature affects the physical, chemical and biological properties of water; for example, as water temperature rises (up to a certain point), photosynthesis increases, resulting in more plant growth. Oxygen is less soluble in warm water than cold water.
- Temperature of the surface water controls or regulates and moderates local air temperature and humidity. Water has high heat capacity, which is defined as the amount of heat required to raise the temperature of 1 g of water one degree Celcius (1 °C). Coastal areas have less variable temperatures than inland areas, because the heat capacity of water is greater than that of land.

Ocean Salinity (its dissolved salt content).

Mean ocean salinity: 35 psu* (35 ‰). *Psu refers to practical salinity unit. It is also expressed as parts per thousand (ppt or ‰), which means that there are 35 grams of dissolved salts in 1 kg of water. Therefore, 1 g/kg = 1 ‰ = 1 psu.

Range of the open ocean's salinity: 33 psu to 37 psu.

Six elements (chlorine, sodium, magnesium, sulfur, calcium and potassium) constitute over 90% of the total "salts" dissolved in the oceans (Fig. 11).

Because pure water is a poor conductor of electricity, it is the impurities in water, such as dissolved salts, that enable water to conduct electricity. Hence, measuring conductivity of water is a good indicator of the total level of impurities, i.e.,

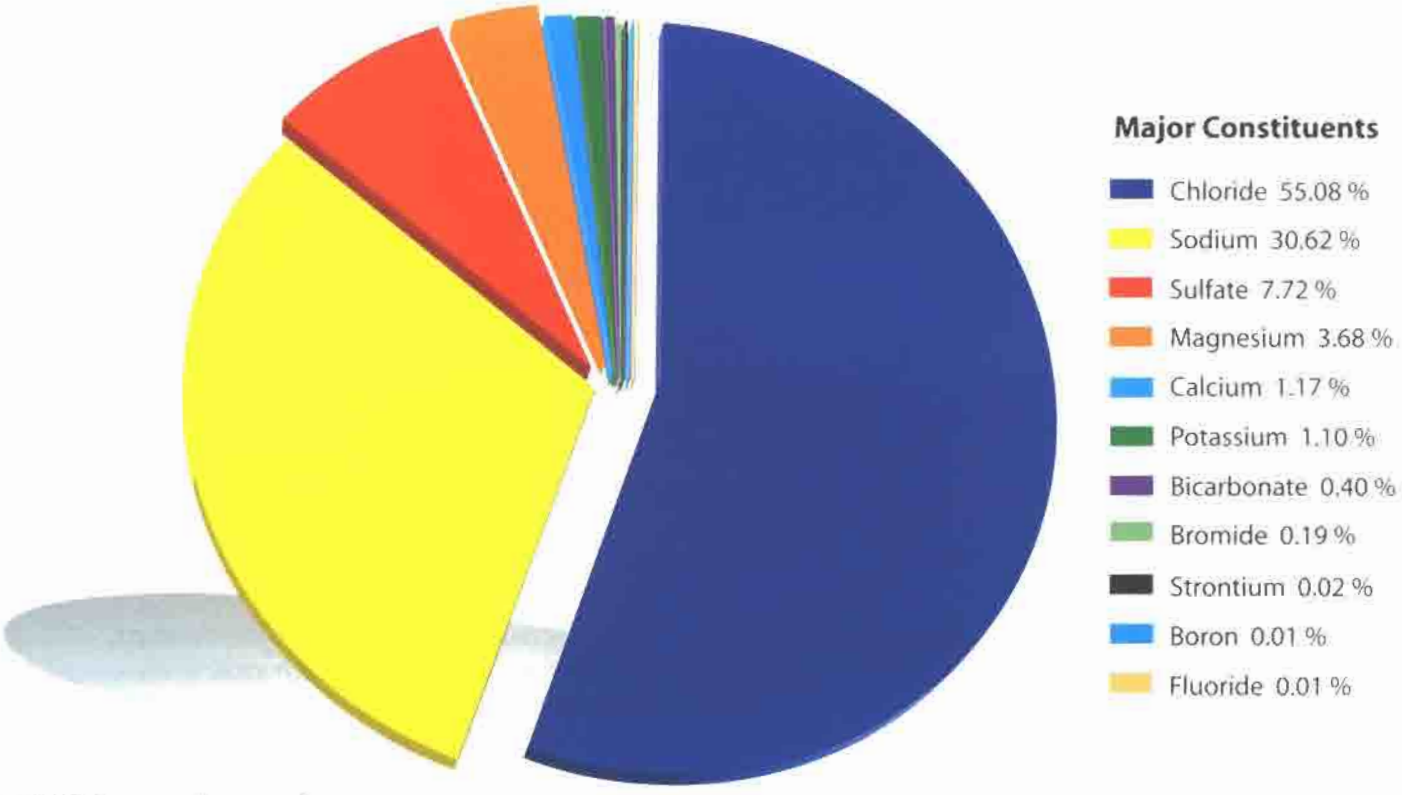


Fig. 11. Major constituents of seawater.

total dissolved salts in the water. The more dissolved salts in water, the greater its electrical conductivity. In oceanographic surveys and research studies, in situ salinity is usually determined by electrical conductivity. A CTD is the instrument of choice of most scientists today to perform this measurement task. It measures conductivity (C), temperature (T) and depth (D).

Salinity values vary with location, depth, season, and with tide. The region of rapid change in salinity with depth is called the halocline (halos=salt). Major processes responsible for differences in salinity values among different areas are: evaporation, precipitation and mixing. Where evaporation exceeds precipitation, salinity values are high. In areas of high rainfall, such as in the equatorial regions, salinity values are lower. High salinity, or dilution, is found usually in coastal waters or in partially enclosed seas. Such extremes are due largely to excessive runoff from the land, river discharge, or to high evaporation rates and little mixing with other waters, as in the Red Sea, Arabian Gulf and the Mediterranean Sea.

Salinities of the Ocean and Different Seas:

- Mean ocean salinity: 35 psu*
- Saltiest sea is the Dead Sea (350 psu).
- The Arabian Gulf has a salinity of ~ 41 psu.
- The Baltic Sea is the world's least salty sea, with salinities varying between 5 and 15 psu (mean of ~ 8 psu). This is due to the many rivers flowing into the Sea.
- The Black Sea has a salinity of < 20 psu.
- The Caspian, the world's largest inland sea, is of regional interest because it is the source of most of Kuwait's imported caviar. The salinity of the Caspian is about 13 psu.

Why Measure Salinity?

Because salinity has a large dynamic range in the coastal waters, it is considered as a critical variable for understanding and predicting biological and physical processes and their interactions with the food web, weather, and commerce. Knowledge of salinity is important in the following studies:

- Long-term time-series measurements of salinity are important to climate studies.
- The majority of global precipitation occurs over the ocean. Therefore, knowledge of sea surface salinity could lead to a better model of the global hydrological cycle and a better understanding of the most important greenhouse gas and water vapor.

- Salinity has always been recognized as important in the Gulf's coastal regions. The salinity of the northern waters of the Arabian Gulf has been changing, e.g., salinity of the waters of Khor Al-Sabbiya dropped from 36 psu prior to 1993 to a mean of 22 psu during 1993-1998 due to the impact of the new man-made Third River in Iraq. Salinity in Kuwait's water rose again during 1999-2002, and reached the pre-1993 level. These changes have implications to the biological productivity and the fisheries resources of Kuwait.

Importance of Temperature and Salinity

- To understand coastal processes, salt content and temperature of coastal waters are two fundamental parameters that must be measured, each providing different clues as to the processes at work in the system.

- Temperature provides information related to heat exchange, whereas salinity provides information about movement and dilution of waters in the coastal ocean.
- Integrated temperature and salinity are indicators of transport, mixing, stratification and frontal boundaries. Thus, salinity *gives us unique and easily acquired information* about issues of great importance to the coastal ocean.

Salinity affects ecosystem functions, and is an essential variable to be measured for studies related to coral growth, oyster diseases, nursery grounds, development of harmful algal blooms, survival of invasive species from ballast water discharge, understanding of the implications of controlling river flow, coastal processes and in aquaculture site selection.

Density. Density is the mass of a substance per unit volume = g/cm^3.

- Pure water has a density of 1.0000 g/cm^3 at 4 °C. Due to the dissolved salts, the average seawater density is 1.025 g/cm^3. The density of seawater depends on both its salinity and temperature. Water with a high salinity is denser than low salinity water; cold seawater is denser than warm seawater of the same salinity.

Seawater (in contrast to pure or fresh water) has its greatest density at its freezing point (-1.9°C). Salt lowers the temperature at which water freezes. Sea ice is mostly fresh water, because salt from seawater is not incorporated into the ice crystaline structure. Therefore, ice floats because it is less dense than water, and, therefore, ice and its snow cover (2-3 m) insulate bodies of water and help keep the underlying water from freezing.

- Changes in temperature and salinity result in a change of density with depth.

- Heating a substance leads to expansion and, therefore, a decrease in the density (mass per unit volume). Conversely, cooling a substance increases its density.

- Density (sigma-t) is a "derived quantity". It is calculated from observations of temperature and salinity.

- A pycnocline (pycno = dense) is a region where there is a strong density gradient. In another words, the increase in water density over a range of water depth, which is caused by a combination of decreasing temperature and/or increasing salinity, is called the pycnocline.

- Temperature is the most important factor defining density. Changes in density of seawater are caused by seasonal heating and cooling, one of the processes that generate ocean currents. Changes in the amounts of salts dissolved in seawater also influence the density.

- The density of seawater is one of the most important processes that control the motion of the ocean. Small density differences caused, for example, by differences in surface heating or cooling, can produce very strong currents. Therefore, the determination of seawater density and its variation is one of the most important tasks in physical oceanography and in studies of circulation patterns.

Underwater Pressure.

- Pressure in the ocean waters increases with increasing depth due to the weight of the overlying water.
- The pressure increases at a rate of 1 atmosphere (atm) for every 10 m (33 ft) of depth (1 atm = 1,016 dynes/cm^2 or 15 lb/in^2).
- The majority of the deep ocean is under 211 to 633 kg/ cm^3 or 3000 to 9000 pounds/in^2 of pressure.

Sound in the Ocean. The speed of sound in seawater depends on temperature, salinity, and depth. Sound travels faster as seawater becomes warmer or saltier. It also travels faster as the pressure in seawater increases with depth. The slowest sound speeds are often found below the surface, and the fastest are in deep waters.

Light. Light or electromagnetic radiation is the transmission of energy in the form of waves having both an electric and a magnetic component. The electromagnetic radiation consists of massless photons (particles), each traveling in a wave-like pattern and moving at the speed of light. Each photon contains a certain amount of energy.

The electromagnetic spectrum (Fig. 12), which can be expressed in terms of energy, wavelength, or frequency, includes the full range of frequencies from radio waves to gamma rays. The only difference between the various types of

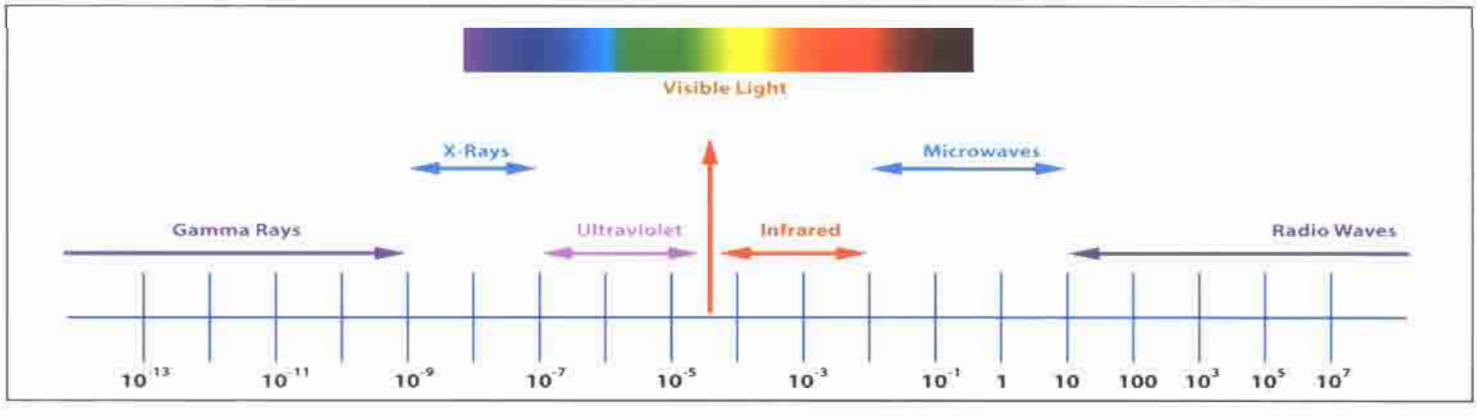


Fig.12. Electromagnetic radiation spectrum.

electromagnetic radiation is in their wavelengths, i.e., in the amount of energy found in the photons. Radio waves have photons with low energies, microwaves have a little more energy than radio waves, and infrared has still more. The most energetic of all electromagnetic waves are gamma rays.
The following table gives approximate wavelengths for selected regions of the electromagnetic spectrum:

Region	Wavelength (cm)
Radio	> 10
Microwave	10 - 0.01
Infrared	0.01 - 7×10^{-5}
Visible	7×10^{-5} - 4×10^{-5}
Ultraviolet	4×10^{-5} - 10^{-7}
X-Rays	10^{-7} - 10^{-9}
Gamma Rays	< 10^{-9}

Wavelengths of the visible region of the spectrum (Fig. 13) range from 700 nm for red light to 400 nm for violet light. The visible spectrum refers to the electromagnetic radiation at wavelengths that the human eye can see. We perceive this radiation as colors ranging from red (longer wavelengths; ~ 700 nanometers) to violet (shorter wavelengths; ~400 nanometers).
The following table includes wavelengths for the different regions of the visible spectrum.

Region	Wavelength (nm)
Red	700
Orange	630
Yellow	550
Green	500
Blue	450
Violet	400

Marine Optics. The optical characteristics of seawater are concerned mainly with light attenuation and the color of the surface seawater. The optical properties of water influence sunlight penetration, which is an important factor in primary production and plant growth. The optical properties, determined by in situ optical sensors or by remote sensing, give information on the distribution of water masses and on their content, such as plankton (tiny floating biota) and non-biogenic particles (silt).

Optical oceanography is concerned with the propagation and interaction of radiation, typically at wavelengths between 350 and 750 nm, with seawater. It encompasses the transfer of radiant energy in ocean waters and the effects of energy absorption on biological productivity. Bio-optical properties of seawater include measurements of variables, such as underwater light (photosynthetically available radiation or PAR, photons s^{-1} m^{-2}), light attenuation, light absorption and scattering, turbidity, water clarity, colored dissolved organic matter (CDOM), chlorophyll (biomass of microscopic or tiny aquatic plants called phytoplankton) and fluorescence. The portion of the sun's energy spectrum of most importance for plants to carry out primary production is the wavelength band between 400 nm and 700 nm (Fig. 13). This is the wavelength interval where chlorophyll (green pigment in plants) can absorb and utilize photons.

Light Penetration in the Ocean. Most of the light is absorbed or scattered within the top few meters of the ocean's surface. Light absorption in the sea reduces the amount of visible light rapidly with depth. Absorption of radiant energy is greater for the long wavelengths of light (e.g., red) and less for shorter wavelengths of light (e.g., blue). Therefore, the

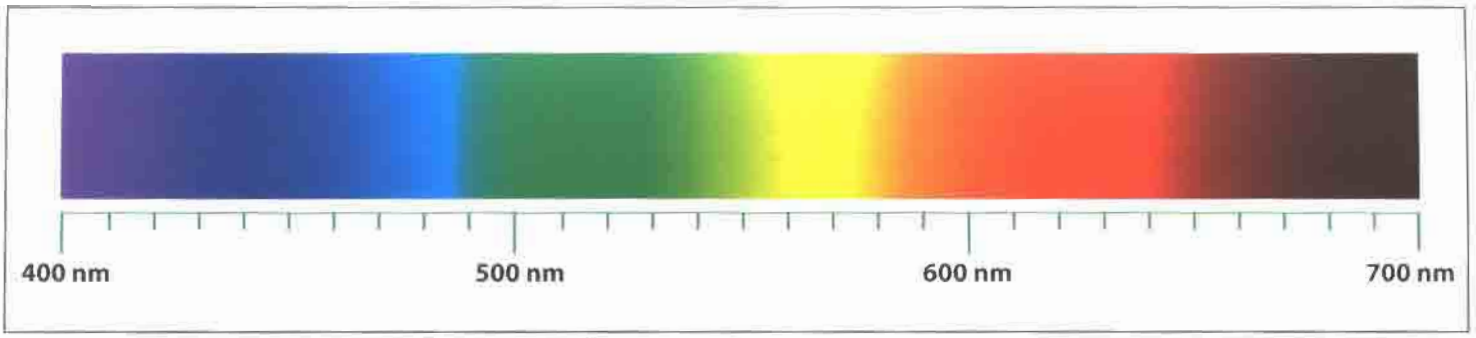


Fig. 13. The portion of the Sun's energy spectrum of importance for primary production (wavelength band between 400 nm and 700 nm).

colors that one can see beneath the sea depend on the wavelength of light available to illuminate an object. For example, a white plate will appear light blue underwater because the long wavelengths of light, which include the red colors, have been absorbed in the surface water and only shorter wavelengths of light associated with blue colors remain to illuminate the plate underwater.

- The intensity of light decreases rapidly with water depth, even in clear oceanic waters:
  - only 73% of the surface light reaches a depth of 1 cm (less than a half inch);
  - only 44.5% of the surface light reaches a depth of 1 m (3.3 ft);
  - 22.2% of the surface light reaches a depth of 10 m (33 ft);
  - 0.53% of the surface light reaches a depth of 100 m (330 ft); and
  - 0.0062% of the surface light reaches a depth of 200 m (660 ft).

- Hence, by 100 to 200 m deep, virtually all of the solar radiation has been absorbed.
- The minimum energy supply necessary to maintain photosynthesis is 0.003 cal per cm^2. Under most conditions this level of energy, that is, enough for photosynthesis, is only available to the upper 200 m of the sea. The surface layer of water where photosynthesis can take place is called the euphotic or photic zone.

Measurement of underwater irradiance is made by a photometer or light sensor (optical sensor).

Transparency.

- Transparency is a measure of the water clarity of a body of water. Penetration of sunlight into seawater determines the depth to which algae (pelagic and benthic) can grow, and their relative amount of growth.
- Water is transparent to visible light (although not to ultraviolet or infrared light).
- Water is colored by the presence and action of some bacteria, phytoplankton and other organisms, by dissolved organic matter from decaying plants, sewage and chemical discharges, storm and land runoff, and by resuspension of bottom sediments.
- Transparency varies with the amount of substances in the water. Hence, transparency decreases as water color, suspended sediments, or algal abundance increases.

How to measure transparency?

Two common methods are used to measure the transparency of water, or the degree to which light penetrates water: the Secchi disk and the turbidity tube.

The Secchi depth (obtained by the Secchi disk) is a measure of the water clarity or transparency. The Secchi disk measurement of water clarity is an approximate evaluation of the transparency of water; it is used primarily for its simplicity. The Secchi disk originated with Father Pietro Angelo Secchi (1865), an astrophysicist and a scientific advisor to

the Pope, who was requested to measure transparency in the Mediterranean Sea.

The Secchi disk (Fig. 14) is a white plate, about 25 cm in diameter, divided into four quadrants painted black and white. It is used to measure how deep a person can see into the water, in other words, it measures light penetration in the water column. The Secchi disk is lowered over the side of a research vessel into the water by unwinding the waterproof tape to which it is attached, until the observer loses sight of it, and then the disk is raised until it reappears and its black and white markings become visible. The depth of the water where the disk vanishes and reappears is the Secchi disk reading (recorded to the nearest meter).

Most natural waters have transparency or Secchi depth (Ds) ranging from one meter to a few meters. In highly productive waters, in turbid waters or in waters with high concentrations of suspended solids, a low value (measurements of less than 1 m) would be expected. In clear, unproductive coastal waters, and in areas around coral reefs, transparency can reach 30 to 40 m.

The turbidity tube (Fig. 15) is like the Secchi disk; it is a simple and easy way to estimate water clarity. It measures turbidity in Nephelometric Turbidity Units or NTUs for flowing or shallow waters, especially where use of a Secchi disk is impractical. The turbidity tube is a clear plastic tube, about 1 m long (depending on transparency of water at the site to be sampled) and 4.5 cm diameter. Wavy lines or an image (a decal with black and white area) is found at the bottom of the tube. The water sample is poured slowly into the tube until the image on the bottom of the tube is no longer visible or distinguishable when looking to the image directly through the water column. The depth of the water in the tube is recorded to the nearest 1 cm. The NTU values are found on the scale on the side of the tube.

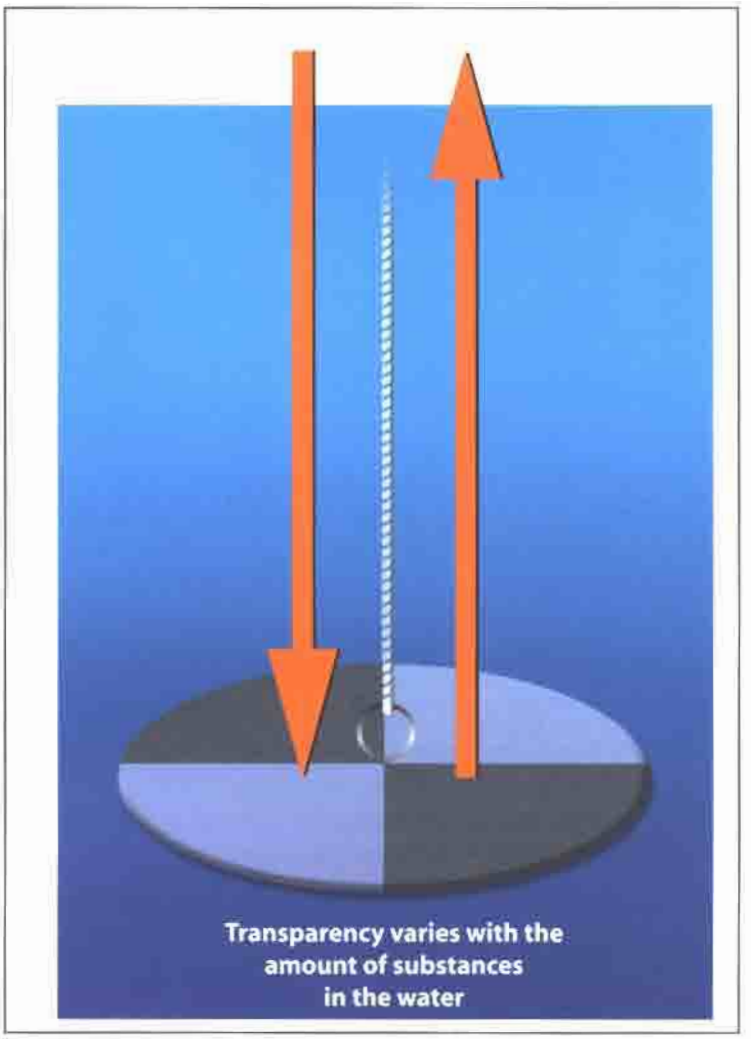


Fig. 14. Secchi disk measures light penetration through the entire water column.

Turbidity.

- Turbidity is the inverse of transparency. It indicates the degree to which water contains particles or suspended matter (silt, clay, inorganic or organic compounds as well as plankton) that cause backscattering and absorption of light.
- High turbidity is caused by a high content of silt or organic particles. Turbidity usually increases after rainfall. Industrial discharge and stormwater drains can contribute large quantities of silt and suspended matter to the sea, therefore, increasing the turbidity level.
- High turbidity reduces the transparency of seawater and reduces the amount of light available for photosynthesis of phytoplankton and benthic algae. This results in the drop of dissolved oxygen level of the seawater, a possible increase in seawater temperature because suspended material absorbs heat from the sun, increases in some pollutants (metals, pesticides and nutrients attach to particles in water), and decreases in biodiversity.

- Reef-building corals require light and are also greatly inhibited by turbidity. Corals survive poorly where suspended sediment is deposited from the water column. Particles in highly turbid waters can clog the gills of fish.
- Because much of the particulate matter in most marine waters is organic, heterotrophic organisms like bacteria increase in abundance with turbidity.
- Turbidity is measured by a turbidity sensor (turbidimeter).
- The turbidimeter or turbidity sensor mounted on a CTD measures turbidity in NTU (Nephlometeric Turbidity Unit; the standard unit used by most water collection agencies and organizations). The smaller the value obtained, the less turbid the water.

Total Suspended Solids. Total Suspended Solids (TSS) are the solid particles that occur in suspension in the water column and can be trapped by a filter of 0.45 µm pore-size. They are composed of organic (living and dead plant and animal matter) and inorganic fractions (such as silt).

High TSS can block light from reaching submerged vegetation and the tiny algae living in coral polyps. As the amount of light passing through the water is reduced, photosynthesis slows down. Reduced rates of photosynthesis cause less dissolved oxygen to be released by plants into the water . If light is completely blocked, bottom dwelling plants will stop producing oxygen and will die. As the plants decompose, bacteria will use up even more oxygen from the water. Low dissolved oxygen will likely lead to fish kills. High TSS can also cause an increase in surface water temperature, because the suspended particles absorb heat from sunlight. This can cause dissolved oxygen (DO) levels to fall even further (because oxygen is less soluble in warmer waters).

Total suspended solids are measured by filtering the water sample through a pre-weighed filter (0.45 µm pore-size filter). The residue retained on the filter is dried in an oven at 105° C until the weight of the filter no longer changes. The increase in weight of the filter represents the total suspended solids.

Total Dissolved Solids. Total Dissolved Solids (TDS) are solids in water that can pass through a filter of 0.45 µm pore-size. TDS is a measure of the amount of material dissolved in water. This material can include carbonate, bicarbonate, chloride, sulfate, phosphate, nitrate, calcium, magnesium, sodium, other ions, and organic molecules. A certain level of these ions in water is necessary for aquatic life. If TDS concentrations in the water are too high or too low, the growth of many marine biota can be limited. Similar to TSS, high concentrations of TDS may also reduce

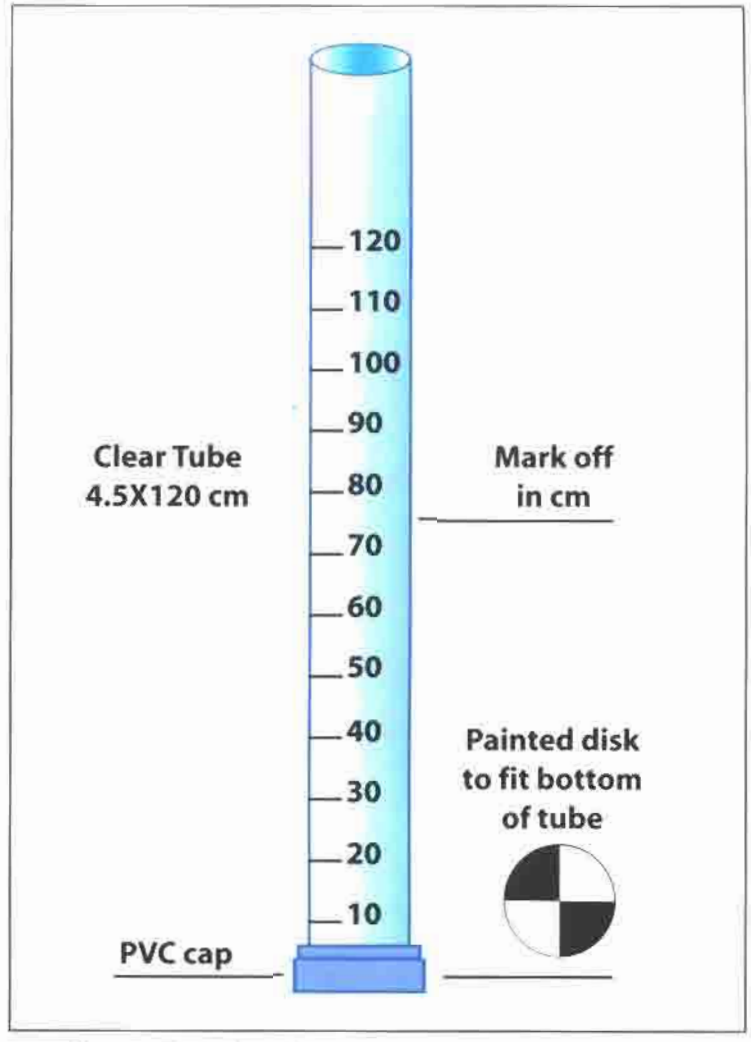


Fig. 15. Turbidity Tube.

water clarity, contribute to a decrease in photosynthesis, combine with toxic compounds and heavy metals, and lead to an increase in water temperature.

TDS is also used to estimate the quality of drinking water, because it represents the amount of ions in the water. Water with high TDS often has a bad taste and/or high water hardness, and could result in a laxative effect. Sodium ions in the water are of concern for those with high blood pressure. To measure TDS, the water sample is filtered, and then the filtrate (the water that passes through the filter) is evaporated in a pre-weighed dish and dried in an oven at 180 ° C, until the weight of the dish no longer changes. The increase in weight of the dish represents the total dissolved solids, and is reported in milligrams per liter (mg/l).

Total Solids. Total solids includes both total suspended solids (the portion of total solids retained by a filter) and total dissolved solids (the portion that passes through a filter).

The Chemical Properties of the Oceans and Seas

pH. pH is a measure of the acidity or the alkalinity of a solution. Acids are characterized by their ability to contribute H^+ ions in aqueous solutions. pH is a mathematical function that indicates the amount of H^+ present in the water, and is calculated using the equation:

$pH = -\log[H^+]$

- The acidity or pH of water is defined as the negative log 10 of the activity of hydrogen ions.
- The activity of hydrogen ions in distilled water is 10^{-7}; therefore, the pH is 7 (neutral).
- The pH scale runs from 0 to 14 (Fig. 16).
- The smaller the pH value, the more acidic the sample.
- Acids have a pH from 1 to <7, 7 being neutral, and bases have a pH from >7 to 14.
- Natural, unpolluted rain has a pH between 5 and 6; most acidic rain has a pH of about 4.
- Ocean water has a pH of about 8, making it a mildly basic solution. It is absolutely essential that the pH of seawater sample is maintained between a pH of 7.8 and 8.3.
- If dissolved carbon dioxide is supplied in great quantities, e.g., during the organic decay process in stagnant shallow waters, the pH may decrease to 7.5. In contrast, high local rates of photosynthesis in shallow waters consume carbon dioxide and can raise the pH to 9.
- The pH of a body of water influences most of its chemical processes.
- pH is measured by a pH meter or with a CTD equipped with a pH sensor.

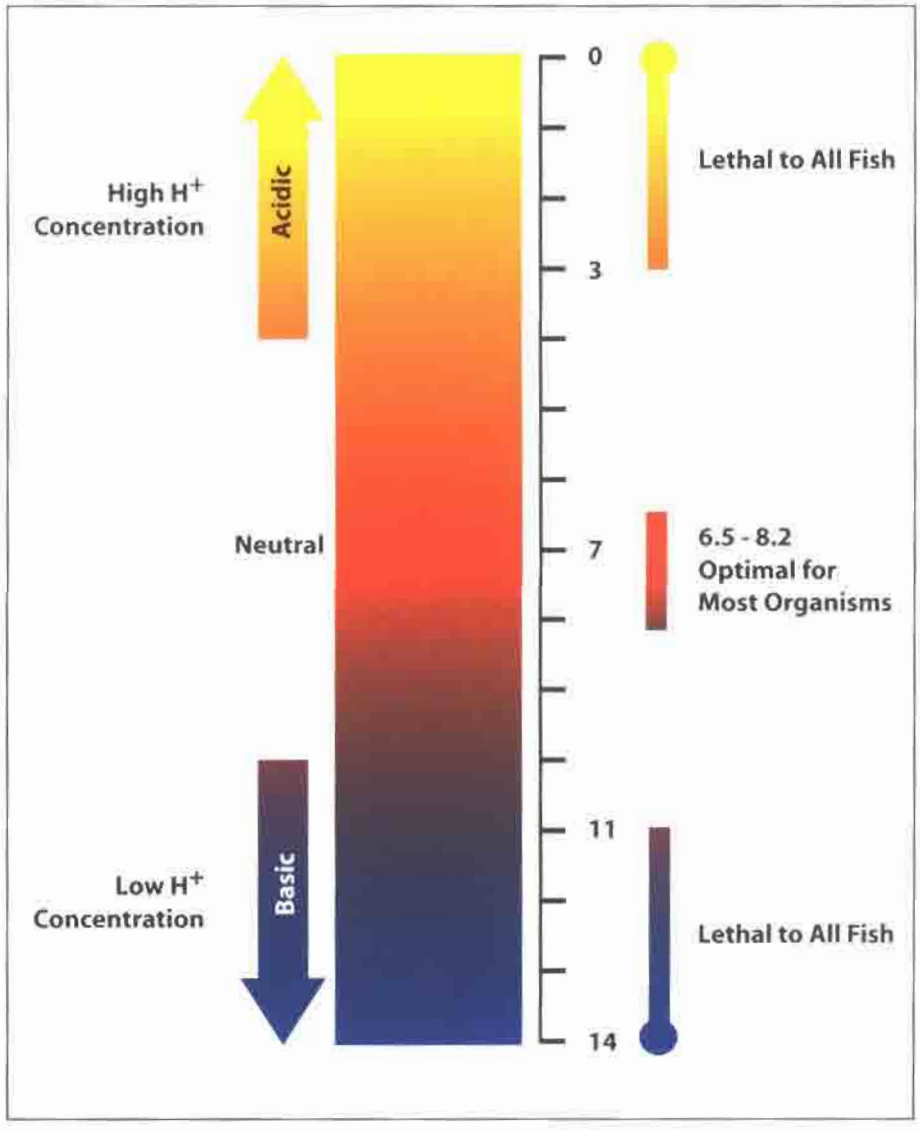


Fig. 16. The pH Scale (0-14).

Alkalinity. Alkalinity is a measure of the amount of alkaline materials in the water, or a measure of the acid buffering capacity of a solution, and its ability to resist a decrease

in pH when acids are added (acids are produced by biological action and combustion of fossil fuels). Therefore, the alkaline materials act as "buffers" to resist changes in the pH. Alkalinity is generated as water dissolves rocks containing calcium carbonates, such as calcite and limestone. When a body of water has too little alkalinity, typically below 100 mg/l (100 ppm), a large influx of acids from a big rainfall or rapid snow-melt event in the spring could temporarily consume all of the alkalinity and, hence, drop the pH of the water to levels harmful to fish or zooplankton. If a water body has high alkalinity, the pH of the water is more stable.

Natural seawater alkalinity levels allow hard corals and coralline algae to properly secrete new skeletal material. When alkalinity levels drop, the carbonate ions needed are not available and the process slows down or stops.

Natural seawater alkalinity is between 100 to 150 ppm (2.1 and 2.5 meq/l).

If the alkalinity is too low (below 80 ppm), there can be rapid fluctuations in pH, which means that there is insufficient "buffer" to the pH. High alkalinity (above 200 ppm) results in the water being too buffered.

Dissolved Oxygen.

- Dissolved oxygen is a measure of the concentration of oxygen that is available in seawater for marine plants and animals. It is a fundamental requirement for the maintenance of balanced populations of fish, shellfish and other aquatic biota.
- The average dissolved oxygen concentration in seawater is 5 ppm (5 mg/l) or 3.5 ml/l, whereas the average concentration of oxygen in the air is 200,000 ppm.
- Most estuarine and coastal animals can tolerate short exposures to reduced dissolved oxygen concentrations without apparent adverse effects. However, prolonged exposures to dissolved oxygen concentrations below five milligrams of oxygen per liter (mg/l, or parts per million) may result in altered behavior, reduced growth, adverse reproductive effects and possible mortality to sensitive species and juveniles. Moreover, very low concentrations of dissolved oxygen (below 2 mg/l) for one to four days results in death to most aquatic animals, especially during summer months when metabolic rates are high. In addition, aquatic populations exposed to low dissolved oxygen concentrations may be more susceptible to adverse effects of other stressors (e.g., disease and toxic substances).

- The concentration of dissolved oxygen varies with location and time of day. Oxygen is transferred from the atmosphere into the surface waters by diffusion.

- The distribution of oxygen in the ocean is controlled through: exchange with the atmosphere; and the biological processes of photosynthesis (oxygen production) and respiration (oxygen consumption).

- Oxygen from the atmosphere dissolves in seawater at the sea surface. The amount that can be dissolved decreases greatly with increasing temperature and, to a lesser extent, with increasing salinity.

- Active photosynthesis of abundant planktonic organisms (during a phytoplankton bloom) in surface waters can significantly increase the oxygen concentration over short periods of time during the day.

- Respiration or decay of abundant planktonic organisms (bloom die off and organic decay) in surface waters can significantly decrease the oxygen concentration during the night.

- Oxygen concentration can be measured in situ with an oxygen meter (ml/l or mg/l) or by titration in the laboratory. To convert the dissolved oxygen solubility from milliliters per liter (ml/l) to milligrams per liter (mg/l), the value must be multiplied by the constant 1.4276.

Nutrients. The most important inorganic nutrients in seawater are phosphorus, nitrogen and silicon. These primary nutrients are consumed by plants and are required for phytoplankton growth. In turn, these nutrients are released by phytoplankton respiration and, after death or decay. Phytoplankton consists of different groups, including dinoflagellates and diatoms.

- If a nutrient is scarce in comparison with demand, it is a limiting nutrient. The limiting nutrient would be the first one to be completely consumed. The factor that makes a nutrient limiting is not the supply alone, but the supply in relation to the demand. In the surface seawater, phytoplankton growth is limited by the available quantities of nitrogen and/or

phosphorus. Available nitrogen is found primarily in the form of nitrate (NO_3), and phosphorus is found primarily in the form of phosphate (PO_4). In addition, silicates (SiO_3) are of importance to diatoms.

- Research by Redfield (1952) on a variety of algal species indicated that, on average, algal cells are composed of carbon (C), nitrogen (N) and phosphorus (P) in the following ratio, which is known as the Redfield ratio (based on elemental composition):
  106 Carbon : 16 Nitrogen : 1 Phosphorus (Redfield, 1934, Redfield, 1952 and Redfield et al., 1963). A ratio with oxygen added is O:C:N:P ratio of 276:106:16:1. For phytoplankton requiring silica, a Si:P ratio of 8 to 12 is often assumed.

When the N:P ratio is, e.g., 3:1, which is below the ideal ratio of 16:1, this indicates that there is much more phosphorus available than nitrogen, and, hence, nitrogen limitation. Increase in phosphorus might lead to a shift in the community of phytoplankton from diatoms to cyanobacteria, which often become dominant at high phosphorus and low nitrogen levels.

On the other hand, when the N:P ratio is high with respect to nitrogen, e.g., 40:1, which is above the ideal ratio of 16:1, this indicates that there is much more nitrogen available than phosphorus, thus phosphorus is the limiting nutrient.

- In nature, addition of a limiting nutrient to a system will stimulate phytoplankton growth. This effect will be amplified throughout the food chain, increasing productivity at all trophic levels. This stimulation can be provided by upwelling of nutrient-rich deep water into the photic zone (upper sunlit layer), river discharges, or storm surges in coastal waters, which resuspend nutrient-rich sediments.
- Oligotrophic waters are characterized by low nutrient levels and low productivity (low chlorophyll-*a* concentration), and eutrophic waters are characterized by being nutrient–rich and productive (high chlorophyll-*a* concentration).
- Nutrients are usually measured by a multi-channel autoanalyzer, which detects low levels as well as high levels of nutrients. Concentration units used for nutrients are microgram per liter (µg/l) or microgram-atom per liter (µg-atom/l) or micromole per liter (µMole/l). To convert µg/l to µMole/l, divide the concentration in micrograms by the relative atomic weight of the element (e.g., for nitrogen, atomic weight is 14.0067).

The Biological Environment of Oceans and Seas

The marine environment is divided into two major realms:

The Benthic Realm. The benthic realm, which refers to the floor of the oceans and seas, extending from the high tide line to the greatest ocean depths. The organisms that live in or on the bottom are called benthos. The benthos include biota that are either on the surface of the sea bottom, or burrow into the bottom sediment; they may be attached to the bottom or mobile, and they play an important role in the food chain. Benthic plants can live only in the euphotic zone, i.e., the uppermost 100–200 m of the ocean, where sunlight penetrates. Corals are an example of benthic biota.

The Pelagic Realm. The pelagic realm consists of all of the ocean and seawater covering the benthic realm (water column). The water column of oceans and deep seas is divided into the euphotic, or photic zone and the aphotic (without sunlight) zone. Plankton, unattached macroalgae and nekton all live in the pelagic realm. Nekton are marine organisms that are strong swimmers, such as fish, squid and whales.

Plankton. The word "plankton" comes from the Greek word planktos, which means wanderer or drifter. Plankton have weak swimming ability, and even modest currents of 1 knot (1 knot = 1 nautical mile per hour) can dominate their direction of travel. The motions of the water control their distribution. The planktonic world is filled with an incredible diversity of predators and prey, primary producers and higher members of the food chain. Most plankters are microscopic in size and live in the euphotic zone. Plankton size is usually measured in microns (1,000 microns or µm, which equals 1 mm or 0.03937 inch). They are classified according to their size (Sieburth et al., 1978) (Table 3). Planktonic organisms are diverse, and are considered as an important food source for many pelagic and benthic animals. Benthic animals that feed on the plankton are generally found in shallow water environments (less than 200 m).

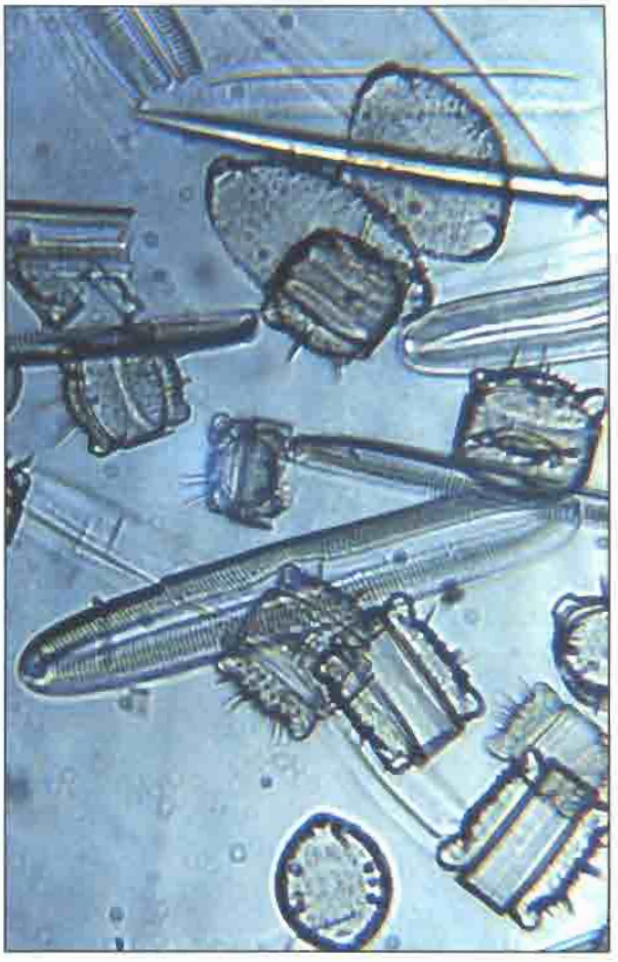
Plankton sampling techniques are size selective. For example, bacterioplankton, phytoplankton and microzooplankton (0.2-200 µm) are collected by a water sampler (e.g., Niskin bottle). Mesoplankton (200-2000 µm) organisms are seived from the ocean directly by towing conical nets with 64 µm or 110 µm mesh size for zooplankton, and for ichthyoplankton (fish larvae) with 333 µm or 500 µm mesh. Therefore, the mesh size used is determined by the type (=size) of planktonic organisms to be collected.

Taxonomically, plankton can be subdivided into animal plankton (zooplankton) including ichthyoplankton (larval fish), plant or algal plankton (phytoplankton), bacterioplankton, consisting of heterotrophic bacteria and cyanobacteria (autotrophic), and virioplankton (pelagic viruses).

Plankton are comprised of autotrophs and heterotrophs. Autotrophs are mainly the primary producers (plants and some bacteria), and utilize inorganic components, such as carbon dioxide, water and nutrients (e.g., nitrogen, phosphorus and silicon compounds) from the environment to manufacture organic material. Organic material differs from inorganic material in that the former has carbon as its main constituent, while the latter does not. Heterotrophs are not capable of converting inorganic matter into organic material, and, therefore, they obtain organic matter by consuming plants (primary producers) or other animals.

Plankton can also be divided into categories based on length of planktonic life. Organisms that spend their entire lives in the water mass (as plankton) are known as holoplankton. Those that spend only portions of their lives as plankton are known as meroplankton. Examples of meroplankton include species of benthic seaweed and kelp, most coral reef organisms, most corals, oysters, crabs, lobsters and fishes, which are planktonic during part of their lives. Examples of holoplankton include bacteria, many unicellular algae (such as diatoms and dinoflagellates), copepods and most comb jellies, which spend their entire lives in the water mass.

Studies of plankton taxonomy and ecology are important to understand marine ecosystems. They are included in monitoring and biodiversity assessment networks, in studies assessing ocean health, plankton dynamics influencing fish stocks, and in global climate change studies.



Various species of phytoplankton.

Virioplankton: Viruses are numerically the most abundant members of aquatic microbial communities. Their numbers (ten billion per liter) exceed the number of potential host cells (e.g., bacteria) by an order of magnitude. Marine viruses range in size from about 40 nm to as large as 120 nm.

A nanometer (nm) = 10^{-3} µm = 10^{-6} mm= 10^{-7} cm= 10^{-9} m; a micrometer (µm) is 10^{-6} meters (m).

Planktonic viruses are pervasive in the marine environment. They influence many biogeochemial and ecological processes. Virioplankton cause appreciable rates of microbial mortality and, therefore, bacteriophages (viruses that attack bacteria) play a role in carbon and nutrient regeneration (e.g., nutrient release from bacterioplankton) in marine systems. Therefore, virally-mediated nutrient recycling may be important in some systems.

Bacterioplankton: Bacterioplankton (free living bacteria in the water column), are actually prokaryotic (without a true nucleus or membrane bound organelles) organisms. They are extremely small in size (<2 µm). The use of modern epifluorescence microscopy techniques has substantially changed our perception of the role of bacteria in aquatic ecosystems. Bacterioplankton include autotrophic as will as heterotrophic bacteria.

Bacterioplankton play a vital role in the mineralization of nutrients and recycling of essential material lost from the food web through the microbial loop (Fig. 17). Hence, bacterioplankton provide a trophic link to higher organisms. Marine bacterioplankton participate in the transfer of carbon in pelagic food webs. Consequently, bacterioplankton are major components of the marine biogeochemical cycles. In some marine systems, bacterioplankton



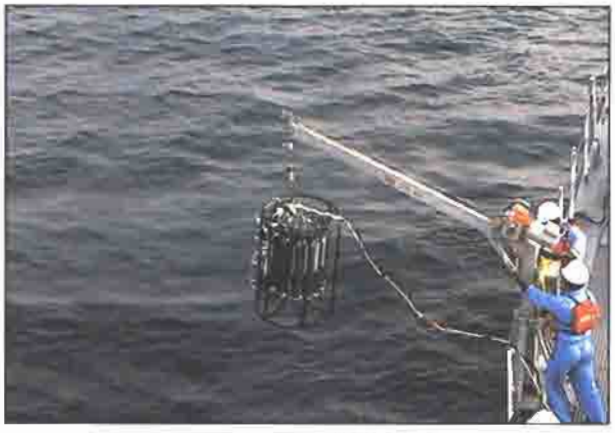
Multiple opening and closing nets and environmental sensing system (MOCNESS) for plankton sampling (photo by Dr. Faiza Al-Yamani).

productivity is comparable with or exceeds phytoplankton primary productivity.

Bacterioplankton includes marine planktonic cyanobacteria (cyano in Latin means blue-green), known as blue-green bacteria (previously known as blue-green algae). Examples of marine cyanobacteria are the autotrophic (in Greek auto = "self", tropho = "nourishment") unicellular *Synechococcus* group (cosmopolitan planktonic cyanobacteria) and the filamentous *Trichodesmium* (*Oscillatoria*) group. Besides bacteriophages (viruses) causing bacterial mortality, predators of bacteria include the following protists: protozoan, ciliates and heterotrophic flagellates.

Phytoplankton: Phytoplankton is a Greek term meaning wandering (planktos) plant (phyton). Generally, individual cells range in size from 20 to 200 µm. Some algae form large clusters, clumps and thread-like groups of considerable size. The phytoplankton group is comprised of a vast, diverse assemblage of organisms, but can be classified into three major phylogenetic groups. Among the most common, Eukaryotes are the **diatoms**, the **dinoflagellates** and the **haptophytes** (coccolithophorids and *Phaeocystis* spp.). Sometimes, the prokaryotic Cyanobacteria (autotrophic bacterioplankton) are included with phytoplankton because of their photosynthetic ability.

Chlorophyll is a complex of pigments, which has its strongest light absorption in the red and blue-violet. All marine and terrestrial plants have **chlorophyll-*a***, which is a green pigment that gives most plants their color and enables them to carry on photosynthesis. Photosynthesis is the process in which green plants utilize the energy of sunlight to manufacture carbohydrates from carbon dioxide and water in the presence of chlorophyll. As a consequence of photosynthesis, oxygen is released as a by-product, which provides most of the atmospheric oxygen vital to respiration in plants and animals.



Rosette sampler with several Niskin bottles.



Bongo plankton net (photo by Dr. Faiza Al-Yamani).

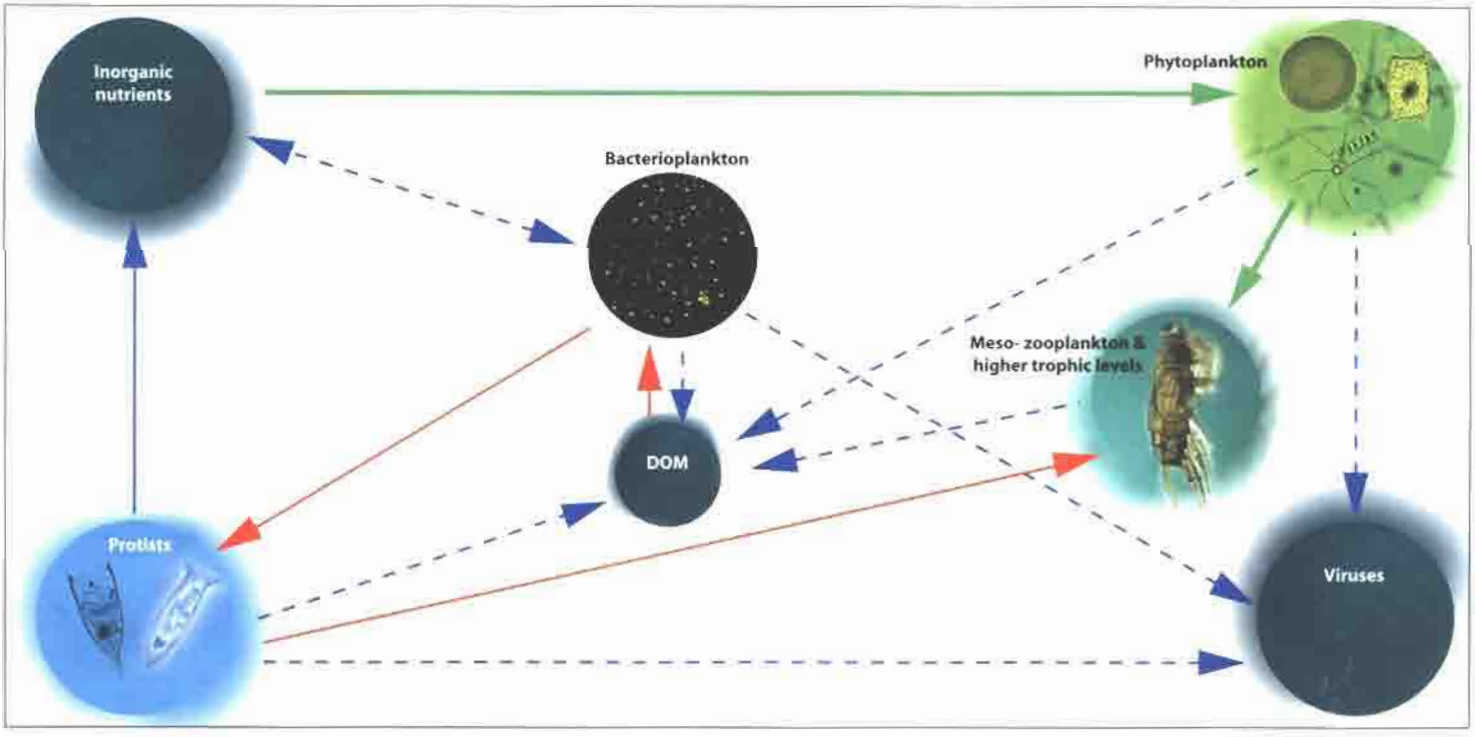


Fig. 17. The microbial loop (red lines) includes bacterioplankton, and heterotrophic nanoflagellates and ciliates (protists). The dissolved organic matter (DOM), which is partly excreted by the phytoplankton and partly by the feeding activities of zooplankton (excretion) is efficiently utilized by the heterotrophic bacteria. Marine protists feed on bacterioplankton, and in turn, protists are eaten by zooplankton. The classical food web is represented by the green lines.

Table 3. Plankton is categorized according to their size.

Classification	Size Range (minimum - maximum	Plankton Type
Femtoplankton*	0.02 µm - 0.2 µm	Virioplankton (marine viruses).
Picoplankton*	0.2 µm - 2.0 µm	Bacterioplankton (free marine bacteria including *Synechococcus).*
Nanoplankton*	2 µm - 20 µm	Fungi, small flagellates, small diatoms (phytoplankton) and protozooplankton; can pass through very fine plankton net of 20 µm.
Microplankton*	20 µm - 200 µm	Most phytoplankton species, foraminiferans, ciliates, rotifers, copepod nauplii.
Mesoplankton*	200 µm - 2000 µm (0.2 mm - 2 mm)	Metazooplankton (e.g., small copepods, cladocerans, larvaceans, small fish larvae).
Macroplankton*	2 mm - 20 mm (0.2 cm - 2 cm)	Large metazooplankton (pteropods, large copepods, euphausiids, chaetognaths) and nekton larvae (fish larvae).
Megaplankton*	> 20 mm (>2 cm)	Nekton, cephalopods, scyphozoans, thaliaceans.

Sunlight is, therefore, considered the ultimate source of life for nearly all plants and animals.

Phytoplankton biomass (chlorophyll-*a* or Chl *a*) is the measure of a mass of photosynthetic pigment per unit volume or per unit area. Typical oceanic range per unit volume is 0.01-2 µg Chl *a* l^{-1} (or mg Chl *a* m^{-3}), and per unit area is 10-70 mg Chl *a* m^{-2}. Chlorophyll-*a* is measured by the following methods:

- High Performance Liquid Chromatography (HPLC).
- Spectrophotometry/fluorometry.
- Remote Sensing of Ocean Colour (satellite sensors).

Photosynthesis is the process whereby plants utilize carbon dioxide, water and solar energy to manufacture energy-rich organic compounds, accompanied by the release of oxygen.

Primary productivity is the rate at which energy is stored (or inorganic carbon fixed into organic carbon) by autotrophic processes (e.g., photosynthetic and chemosynthetic microorganisms). The rate at which carbon-based material is produced

by phytoplankton is crucial to marine ecosystems. Primary productivity is the mass of organisms produced through photosynthesis per unit area and time by plants. It is expressed as: μg carbon/l/d (μg C/l/d), or μg carbon/cm^2/h, or mg carbon /m^2/ d, or g carbon/m^2/yr.

The decomposition rate is the rate at which energy is released (or complex organic carbon compounds broken down into simpler organic carbon compounds or CO_2) by heterotrophic processes (e.g., respiration).

Assimilation Number (assimilation ratio and photosynthetic index): Assimilation number is a synonym for **Pmax** in equations relating photosynthetic rate to light intensity. It is expressed as the rate of photosynthetic carbon assimilation per weight of chlorophyll *a*. [*i.e.*, µg C (µg Chl-*a*)$^{-1}$ h^{-1} or mg C (mg Chl *a*)$^{-1}$ h^{-1} or mg C (mg Chl *a*)$^{-1}$ d^{-1}] and is also known as the maximum chlorophyll-specific production.

Harris et al. (1989) reported the physiological maximum assimilation number (Pmax) is approximately 6.2 mg C (mg Chl *a*)$^{-1}h^{-1}$, while Falkowski (1980) puts the theoretical maximum at 21 mg C (mg Chl *a*)$^{-1}h^{-1}$.

Red Tides: Most of the time, marine waters are characteristically blue. If conditions are right, phytoplankton can sometimes grow and reproduce at a very high rate, creating dense patches, with up to millions algal cells per liter. When a single microalgal species increases in abundance until it dominates the microscopic plant community and reaches such high concentrations that they discolor the water, the phenomenon is called blooming. These blooms of algae are often referred to as a red tide.



Trichodesmium *bloom in Kuwait's waters (photo by Abdul Rahman Abdul Ghaffar).*

The color of the water during blooms or red tide events is due to the dominant pigments within the algae, which are used for trapping sunlight. Different algae have different dominant pigments, thus different colors. Therefore, depending upon the specific algae involved, discoloration of the water may tend to shades of red, pink, violet, orange, yellow, blue, green or brown. However, many of the discolorations due to algae in marine waters are red, hence, the origin of the term "red tide". The term is now associated with the phenomenon itself, so the color of a red tide is not necessarily red, but may be any other color.

High concentrations of toxic (toxin producing) or harmful (e.g., bearing spines) algal species can cause these blooms, which are referred to as harmful algal blooms (abbreviated as HAB). However, non-toxic species can also bloom and harmlessly discolor the water. A benign red tide is a natural phenomenon in Kuwait's waters.

There are 5000 microscopic algae or phytoplankton in the sea. About 300 phytoplankton species occur in concentrations high enough to cause a red tide, and only one fourth of these are harmful. In Kuwait's waters, there are at least 21 species of potentially toxigenic algae (Subba Rao and Al-Yamani, 1998).

There are six kinds of known toxins, most of them are toxic to humans due to consumption of toxin-laden shellfish, such as oysters and other bivalves, or fish consumption (e.g., grouper). Five human syndromes are presently recognized to be caused by consumption of tainted seafood, and one by drinking water:

- Amnesic shellfish poisoning-ASP.
- Ciguatera fish poisoning-CFP.
- Diarrhetic shellfish poisoning-DSP.
- Neurotoxic shellfish poisoning-NSP.
- Paralytic shellfish poisoning-PSP.
- Blue green algal or blue green bacterial toxins in drinking water, which are found in freshwater and brackish water environments.

None of the above syndromes are known to occur in Kuwait.

Zooplankton. Zooplankton is a term derived from Greek and translates to wandering (planktos) animal (zoo). They are heterotrophs, which means that they obtain their energy by preying upon other planktonic organisms, including phytoplankton. The zooplankton assemblage of herbivorous grazers and the primary carnivores as well as phytoplankton (primary producers) are the most important prey for larval and juvenile fish. Zooplankton form an important route for the transport of carbon through the marine ecosystems by processing photosynthetically produced organic matter and passing it up the food web to the higher trophic levels, and down through the water column in the form of faecal pellets and excretion products. In addition, because of their critical role as a food source for larval and juvenile fish, the dynamics of zooplankton populations, their reproductive cycles, growth, and survival rates are all important facets influencing recruitment to fish stocks. Plankton are especially sensitive to physical processes such as currents, turbulence, light, and temperature regimes. Inevitably, variability in these physical processes affects the stability of biological processes.

Zooplankton are diverse, with two main groups (depending on the length of planktonic life):
- **Holoplankton** (permanent plankton) are planktonic throughout their life, such as copepods and chaetognaths.
- **Meroplankton** (transitory or temporary plankton) are planktonic during only a part of their life cycle as egg and larvae, e.g., larval stages of Bryzoans, Echinoderms, Porifera, Crustacea, Mollusca, Annelida and some nekton (e.g., fish).

Examples of main groups of zooplankton include copepods, protists (such as Foraminifera and Radiolaria), cnidarians, ctenophores, nemotodes, annelids, molluscs (pteropods and heteropods), crustaceans (cladocerans, ostracods, mysids, amphipods, euphausids, and decapods) and chordates (thaliaceans or salps and larvaceans).



A copepod from Kuwait's waters (photo by Dr. Faiza Al-Yamani).

Besides being either meroplankton or holoplankton, zooplankton can also be categorized as to where they live:

Pleuston. Those living at the surface of the sea, part of whose bodies project into the air (the air-water interface). They are often treated as a separate category from plankton because they are transported by wind rather by current. Examples are *Physalia* (Portuguese-Man-of-War), *Vellela* and the water bug *Halobates*.

Neuston. Those that live underneath the water surface film or those living in the uppermost few to tens of millimeters of surface microlayer (at the surface film of the water), such as *Janthia* sp. (purple bubble raft snail) and *Glaucus* sp. (nudibranch).

Biodiversity. Biodiversity is a term used to refer to the variety of life forms. It is a measure of the richness of life by its variety, and is a measure of the number of species occurring within a defined region or habitat. Taxonomists examine the flora and fauna of the region or habitat under consideration according to their genus and species names. Genus and species are the terms used to uniquely identify plants and animals.

Taxonomy is the science of classification, which is a system of arranging animals and plants into natural, related groups based on factors common to each, such as structure, embryology, biochemistry, etc.

Basic biological taxa used by taxonomists to classify organisms in descending order are:

Phylum
Class
Order
Family
Genus
Species

Living things are divided into five kingdoms:

- Monera / Bacteria
- Protoctista / Protists
- Fungi
- Plantae
- Animalia

Biogeochemical Cycles and Their Interactions

The environment (i.e., the human surroundings) consists of 5 spheres: the atmosphere (air), the hydrosphere (water), the geosphere/lithosphere (soil), the biosphere (plants and animals), and the anthrosphere (human and industrial activities), which are considered as reservoirs of environmental constituents. They are linked through physical, chemical and biological processes. Chemicals can move from one reservoir to another. The transport of chemicals from one reservoir to another (pathways) is described in terms of biogeochemical cycle. Therefore, biogeochemical cycles are paths of chemical elements (including all the essential elements for protoplasm) passing through from environment to organisms and vice versa. If input of a substance from a source into a reservoir equals the output from a sink (reservoir), the system is in a steady state. When the rate of input exceeds rate of output, a build up of materials takes place in the reservoir (e.g., when pollutants are added at a faster rate than they could be removed by natural processes). If the rate of output exceeds that of input, there is a depletion of natural resources in the reservoir.

Understanding biogeochemical cycles of carbon, nitrogen, sulfur, and phosphorus are important due to their significance in the earth-atmosphere-biosphere system. Many of our current environmental problems are manifestations of disturbed biogeochemical cycles. There is a critical dependence of biological processes on physical, hydrodynamic and chemical processes from micro- (small) to macro- (large) scales, which are involved in carbon fixation, production and energy transfer within food webs; import and export of energy from pelagic and benthic communities; structure and dynamics of marine communities.

The sea bottom is a site of mineralization (degradation of organic matter by organisms) and nutrient regeneration (new production) of deposited organic matter, as well as a burial ground for some of the organic matter. The C:N:P ratio of sedimenting detritus shows a preferential depletion of nitrogen and phosphorus during the early stages of decomposition. Detritus is efficiently remineralized in the sediment, and hence, the regeneration of the elements is mostly determined by the C:N:P ratio of the deposited detritus. Bacterial denitrification causes a deficit in combined nitrogen. This process causes nitrogen to become a limiting nutrient in many marine ecosystems.

Prokaryotic bacteria are essentially bags of enzymes, which require energy. During the process of acquiring energy, they chemically transform many important elements through oxidation and reduction reactions. Consequently, bacteria are responsible for most of the global decomposition of organic matter and the production of greenhouse gases. The biogeochemical cycles of the majority of biological elements are controlled by microbially-mediated processes.

Marine phytoplankton are responsible for about half of the global primary production. Some of the carbon dioxide they fix is exported to the deep sea; some of the silicates (SiO_2) precipitated by diatoms (unicellular algae with cell walls of amorphous silica) and calcium carbonates ($CaCO_3$) precipitated by coccolithophores (nannoplanktonic flagellate algae with a layer of minute calcareous plates) are accumulated in sediments and eventually subjected to diagenesis (post-depositional changes of sediments due to interaction of physical, chemical and biological processes).

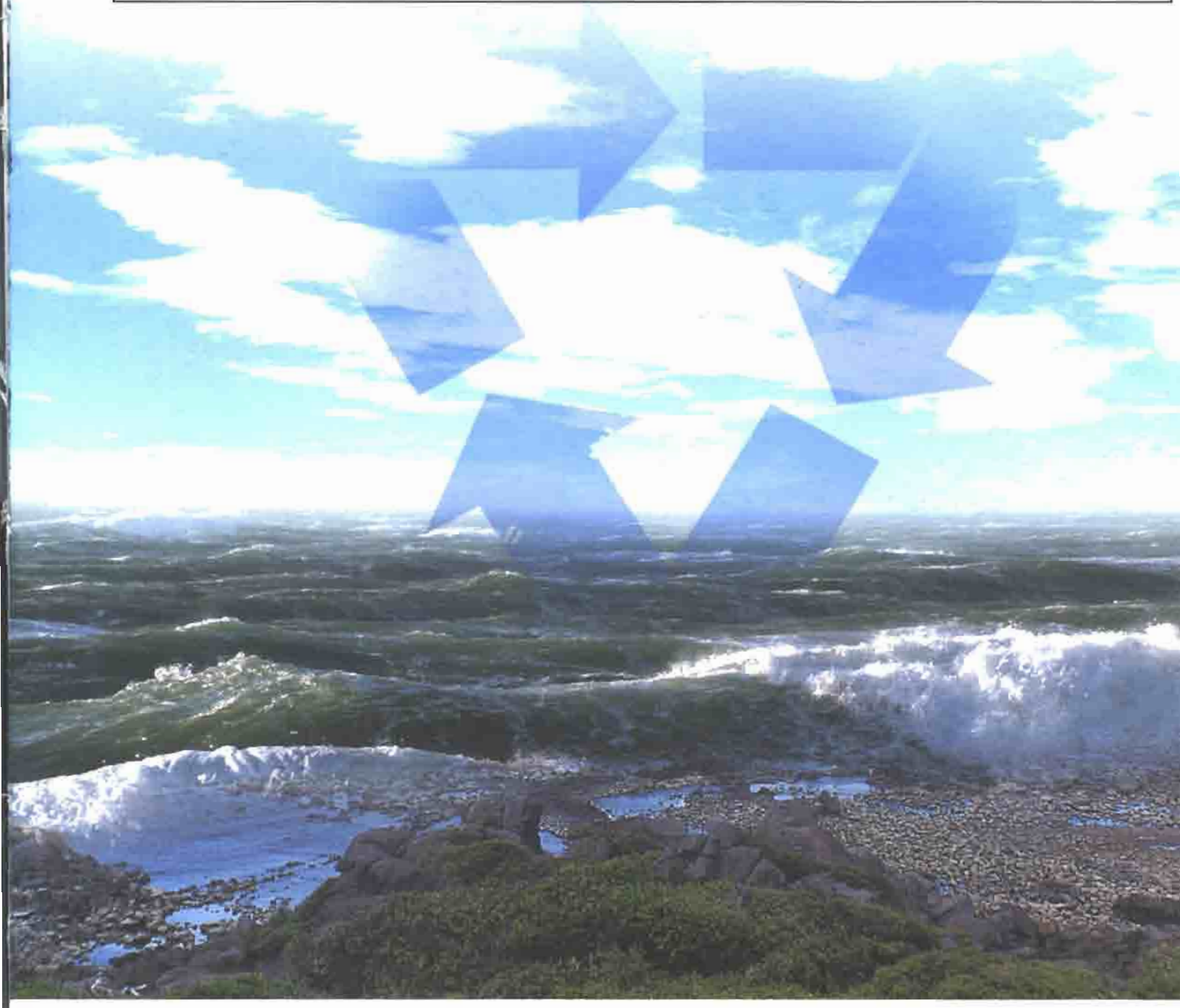
Biogeochemical cycles are those of macronutrients (nutrients constituting the main part of nutrition) such as sulfur (S), nitrogen (N), phosphorus (P) as well as of micronutrients (needed in minute amounts) such as trace metals (Mn, Fe, Co, Ni, Cu, Zn, and Cd). Some trace elements are essential for phytoplankton growth (e.g., Fe), some are toxic (e.g., Hg), and some are both growth promotory and inhibitory as well (e.g., Cd). The interactions between trace metals and macronutrient metabolism in phytoplankton are of great importance to the understanding of the global nutrient cycling.

Zooplankton affect the elemental stoichiometry (deals with calculations about the masses and sometimes volumes of reactants and products involved in a chemical reaction) and material fluxes between particulate and dissolved matter directly through processes associated with the selective consumption and subsequent processing of their food. In addition, the degree of coupling of zooplankton (consumers) and phytoplankton (producers) gives rise to regional and seasonal variations in the abundances of producer stocks, nutrient utilization and recycling efficiencies, and elemental export ratios. Hence, zooplankton has an important role in regional and global biogeochemical cycles.

Human impacts on biogeochemical cycles

Cycle	Human interference	Environmental consequence
Carbon	Fossil fuel combustion, clearing of forests	Global warming
Sulfur	Fossil fuel combustion	Acid rain
Nitrogen	Fossil fuel combustion, Fertilizers	Acid rain, eutrophication
Phosphorus	Detergents and fertilizers	Eutrophication

Source: Miroslav Radojevic and Vladimir N. Bashkin. *"Practical Environmental Analysis"*. The Royal Society of Chemistry, 1998.





Satellite Oceanography

Satellite oceanography or oceanography from space encompasses all aspects of the study of the ocean which use surveillance of the sea from platforms orbiting the earth. The data rate of marine science information arriving from space is many orders of magnitude greater than that from all the oceanographic vessels deployed at anytime in the world's oceans.

Satellites can take measurements over the entire earth's surface in just a few days. Satellites have many applications, such as communications, weather forecasting, dynamical oceanography, and surveillance. Scientists use satellites to detect how the oceans affect the environment, to analyze wave patterns, monitor surface marine life and productivity, analyze ocean tendencies and currents, and acquire synoptic views of the ocean, especially areas hard to reach by ship. However, remote sensors on aircraft and satellites require in-situ verification (field measurements) as well as calibration.

An oceanographic satellite carries instruments and sensors that take measurements of the ocean. For example, the TOPEX/Poseidon altimeter measures the height of the sea surface. The temperature of the sea surface can be measured using an instrument called a radiometer. Radiometer comes from the words "radiation" and "measure", and the radiation being measured is heat. The advanced very high resolution radiometer (AVHRR) is an example of a satellite-based radiometer. AVHRR is used to measure sea surface temperature. Satellite instruments also measure the amount of reflected light of different wavelengths. From space, variations in ocean color can be measured with sensitive instruments, which allow scientists to estimate the productivity of oceans. The Sea Wide Field of view sensor (SeaWiFs) is used to measure the concentration of chlorophyll-*a* (plant green pigments) and to estimate phytoplankton distribution in the sea. Therefore,

oceanographers and marine scientists can use satellites to measure sea surface height (TOPEX/Poseidon altimeter), to track whale migrations (TOPEX/Poseidon altimeter), measure sea surface temperature using AVHRR, and estimate plankton distribution and productivity in the world's oceans (SeaWiFs) as well as high probability areas for fish availability.

International Oceanographic and Atmospheric Research Programs, Projects and Organizations

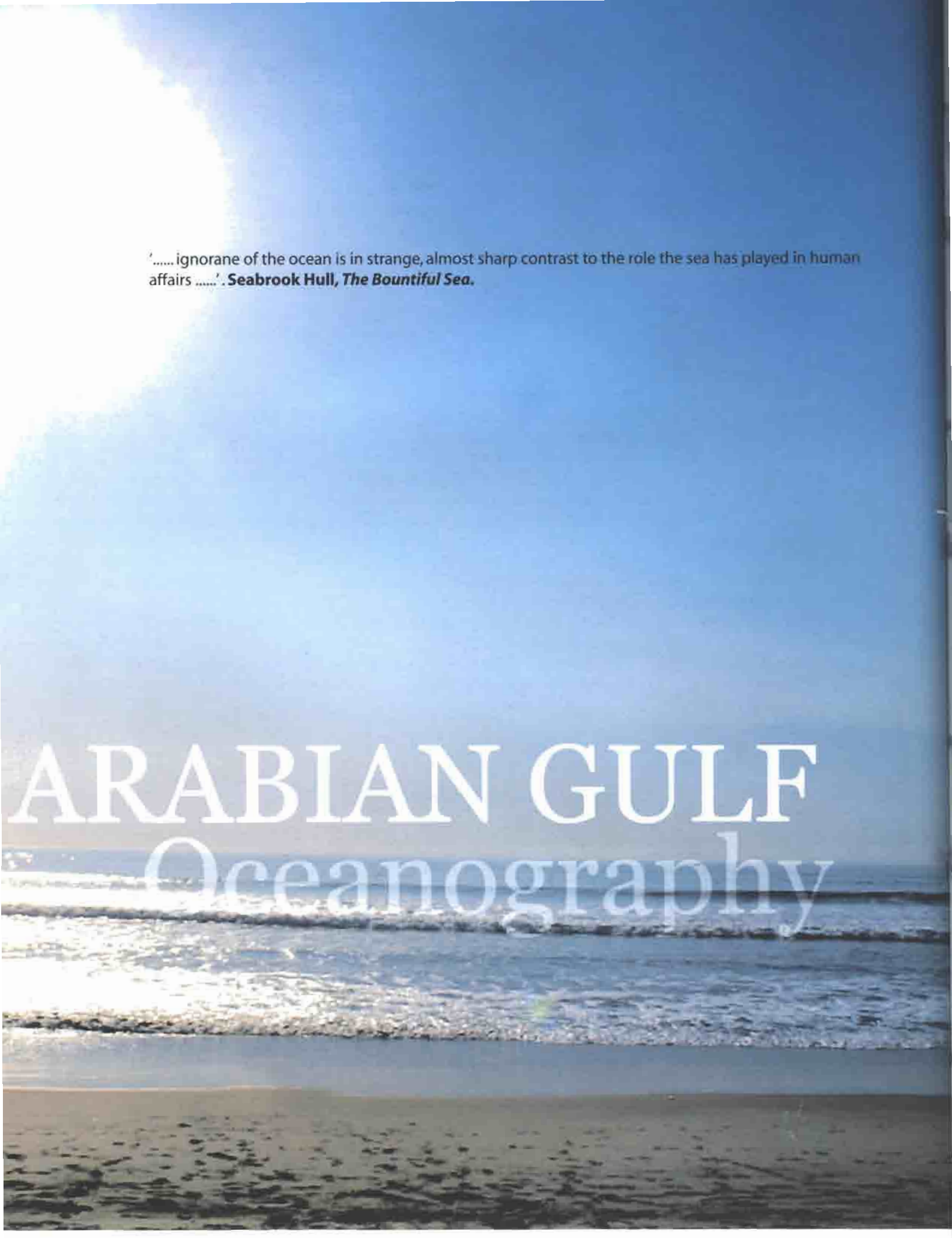
The field of oceanography is a global science of inter-regional nature. There are several international research programs that focus on understanding global changes in the oceans and seas as well as world climate. These programs provide an international, inter-disciplinary framework for the conduct of global change science, a means for co-ordinating activities in various scientific disciplines and for fostering the integration of results towards the development of a holistic picture of global processes and how change affects them. They aim to provide the best possible scientific information for input to the policy process.

GLOBEC (GLObal Ocean ECosystem Dynamics) is one example of an international research program. It was initiated by SCOR (Scientific Committee on Oceanic Research) and the IOC (Intergovernmental Oceanographic Commission) of UNESCO (United Nations Educational, Scientific and Cultural Organization) in 1991. The aim of GLOBEC is to advance our understanding of the structure and functioning of the global ocean ecosystem, its major subsystems, and its response to physical forcing so that a capability can be developed to forecast the responses of the marine ecosystem to global change. GLOBEC's multi-national programs consist of several countries working together on a specific aim or study area. BENEFIT (Benguela Environment and Fisheries Interactions and Training Program) draws on the work of researchers in Namibia, Angola and South Africa and from co-sponsor countries (Germany and Norway) to answer questions concerning the Benguela Current Ecosystem. LIFECO (LInking hydrographic Frontal activity to ECOsystem dynamics) is an European funded program enabling scientists from Denmark, Germany, Norway and the UK to work together to establish the links between frontal activity and ecosystem dynamics in the North Sea and Skagerrak and their importance to fish stock recruitment. OFCCP (Oceanic Fisheries and Climate Change Project) investigates the effect of climate change on the productivity and distribution of oceanic tuna stocks and fisheries in the Pacific Ocean with the goal of predicting short- to long-term changes and impacts related to climate variability and global warming. TASC (Trans-Atlantic Study of *Calanus*) involved scientists from Denmark, the Faroe Islands, France, Germany, Iceland, Norway and the UK in a study of *Calanus finmarchicus* (a key zooplankton species in the north-east Atlantic).

There are several international oceanographic and meteorological organizations and societies that deal with oceanographic and atmospheric research as well as databases. Kuwait is an active member of ROPME (Regional Organization for the Protection of the Marine Environment), and participates in its regional oceanographic research programs, monitoring activities, surveys, workshops and conferences. Examples of relevant programs, organizations and societies include:

American Meteorological Society
American Geophysical Union (AGU)
European Geophysical Society (EGS)
International Oceanographic Data and Information Exchange (IODE)
Integrated Global Ocean Services System (IGOSS)
Global Ocean Observing System (GOOS)
Ships of Opportunity Program
JOINT WMO/IOC Technical Commission for Oceanography and Marine Meteorology (JCOMM)
JCOMM Observing Platform Support Center
Argo Information Center
Global Warming International Center
Inter-American Institute for Global Change Research (IAI)
Intergovernmental Panel on Climate Change (IPCC)
International Association for the Physical Sciences of the Oceans (IAPSO)
International Council for the Exploration of the Seas (ICES)
Marine Sciences Portal for the North Atlantic and the Mediterranean
North Pacific Marine Science Organization (PICES)
Partnership for Observations of the Global Oceans (POGO)
Royal Meteorological Society
Scientific Committee on Antarctic Research (SCAR)
System for Analysis, Research and Training (START)
The Oceanography Society (TOS)
Virtual Center for Decadal Climate Variability Studies
United Nations Framework on Climate Change (UNFCC)
U.S. Global Change Research Program

'..... ignorane of the ocean is in strange, almost sharp contrast to the role the sea has played in human affairs .....'. **Seabrook Hull, *The Bountiful Sea*.**



ARABIAN GULF Oceanography

THE OCEANOGRAPHY OF THE ARABIAN GULF

The Arabian Gulf, a marginal sea in a typical arid zone, is an arm of the Indian Ocean. It lies between latitudes 24 - 30 °N, and has an arid, sub-tropical climate with an average annual rainfall of < 5 cm in coastal Arabia. The Gulf covers an area of 226,000 km^2. It is 990 km long, and its width ranges from 56 to 338 km. It has a total volume of 7000 - 8400 km^3 (Emery 1956, Purser and Seibold 1973, El-Gindy and Hegazi 1996). The entire basin, which is nearly completely surrounded by arid land, lies entirely upon the continental shelf. The main freshwater inflow is from the Shatt Al-Arab River at its northern end. The Gulf's mean surface salinity is about 41 psu. Salinities in the Gulf range from a low of 35 psu or less near the mouth of the Shatt Al-Arab to as much as 70 psu in the Gulf of Salwa, near Qatar. Because of the water shallowness (a few meters deep) and no river input, the waters near Bahrain, Qatar and western United Arab Emirates can reach 50 psu or more; however, salinities near the Strait of Hormuz average 37 psu.

The Arabian Gulf has a mean water depth of 35 m, but depths as great as

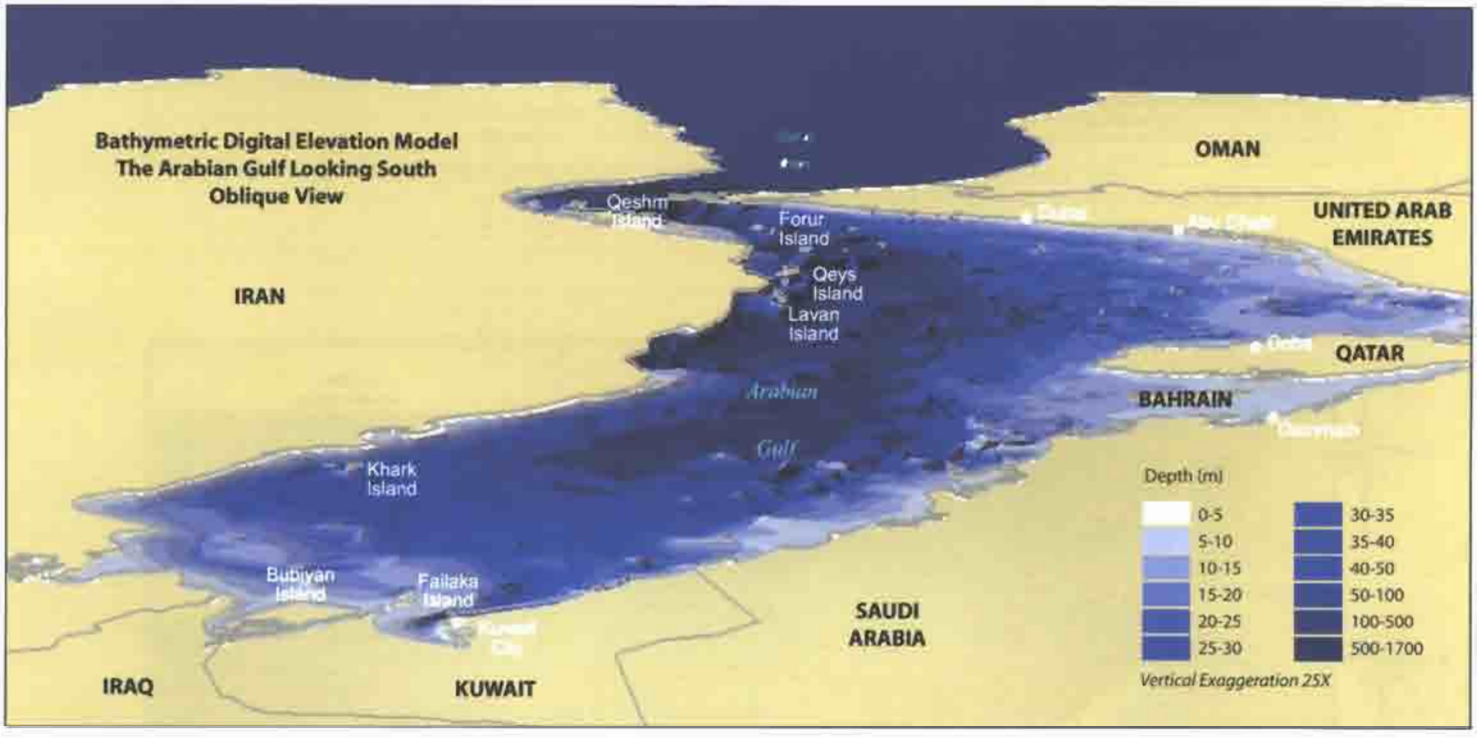


Fig. 18. GIS map showing the water depth in the Arabian Gulf in an oblique view.

107 m occur in some places (Figs. 18-22). The Gulf's waters increase in depth in a southeast direction. Due to the shallowness of the Gulf and the effect of the northwesterly winds, mixing occurs between deep and surface waters. The Gulf is connected to the Gulf of Oman and the Arabian Sea through the Strait of Hormuz (56 km width, 107 m depth), therefore, allowing water exchange between the Arabian Gulf and the Gulf of Oman to occur. The Arabian Sea and the Gulf of Oman are, in comparison with the Arabian Gulf, very deep (2000 m) and less saline (36 - 37 psu).

High salinities are found in the Gulf waters due to high evaporation rates, which exceed the sum of precipitation (annual mean of 34 km^3) and river discharge (annual mean of 37 km^3). Mean evaporative losses from water (about 2m/year) are estimated to be about 326 km^3/year, hence, more water (3365 km^3/year) flows into the Gulf than exits (3110 km^3/year) (Ackleson et al., 1992). The residence time of Gulf waters is about 3.5 years.

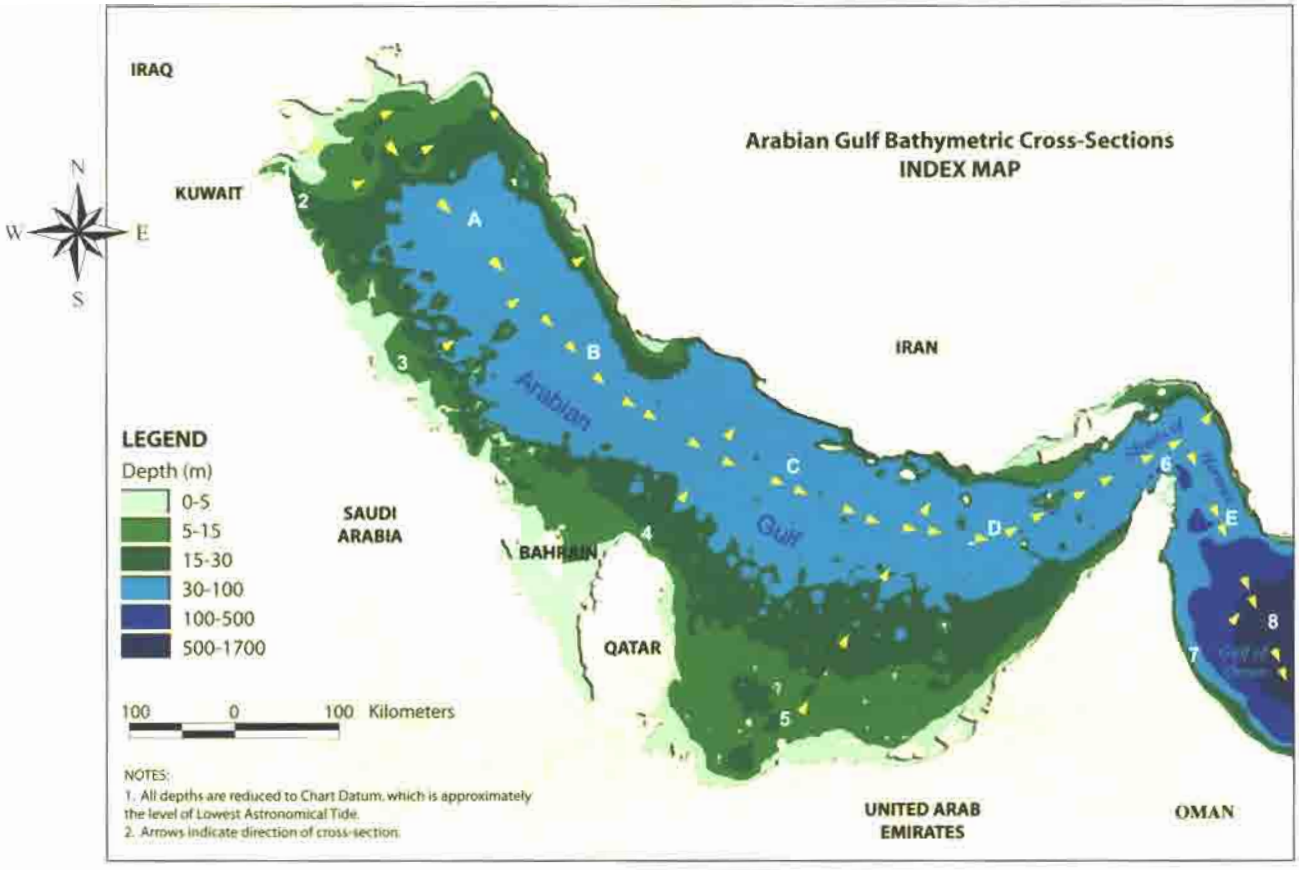


Fig. 19. GIS index map showing the water depth in the Arabian Gulf.

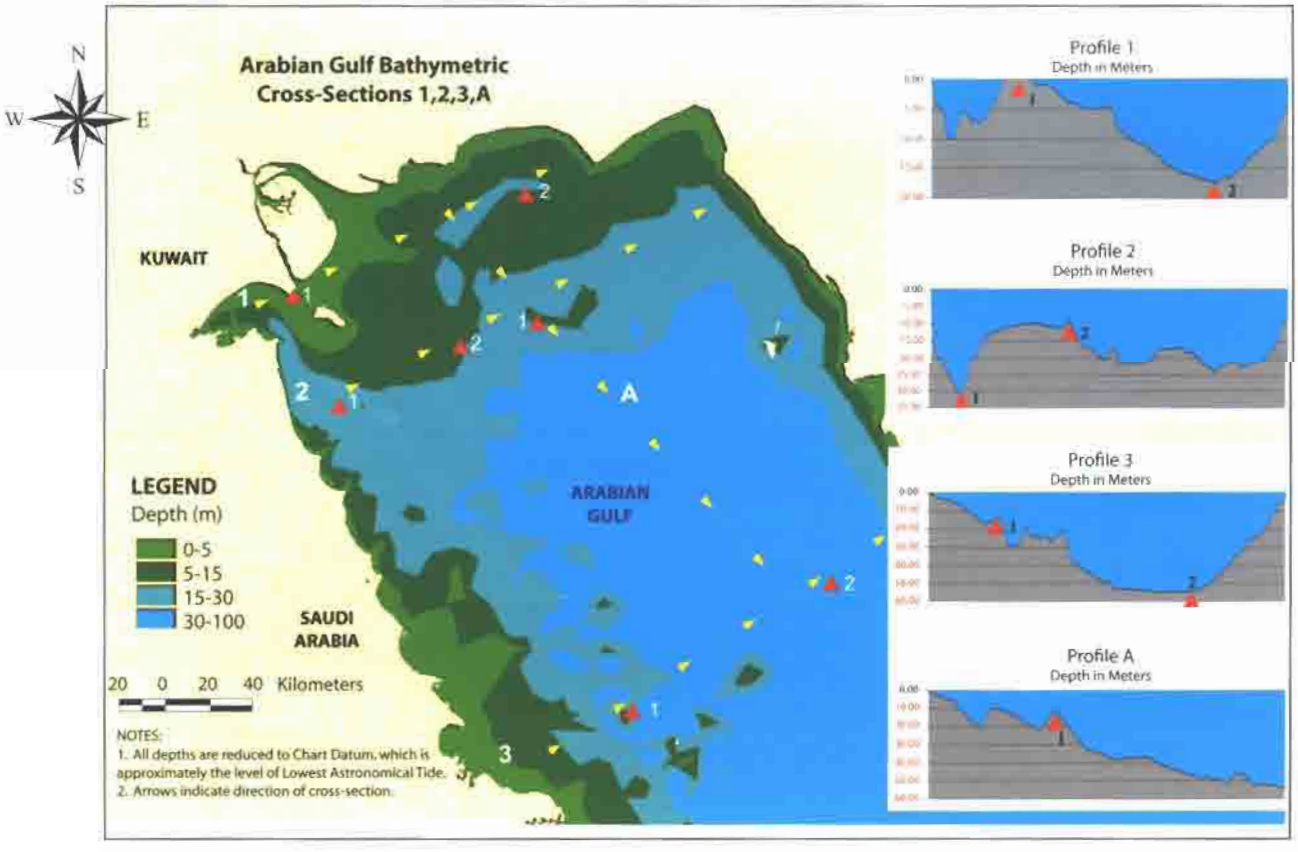


Fig. 20. GIS map showing the water depth in the northern waters of the Arabian Gulf.

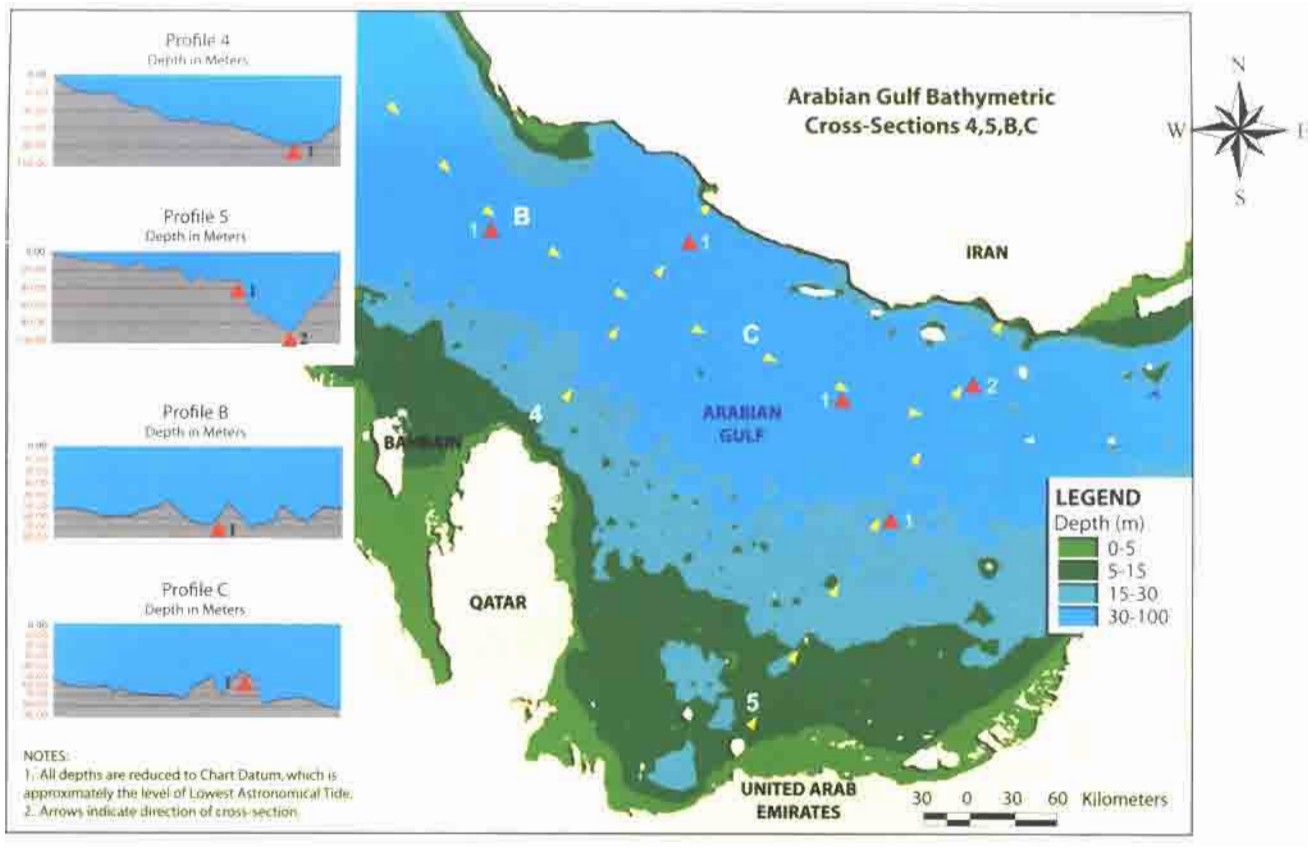


Fig. 21. GIS map showing the water depth in the southern waters of the Arabian Gulf.

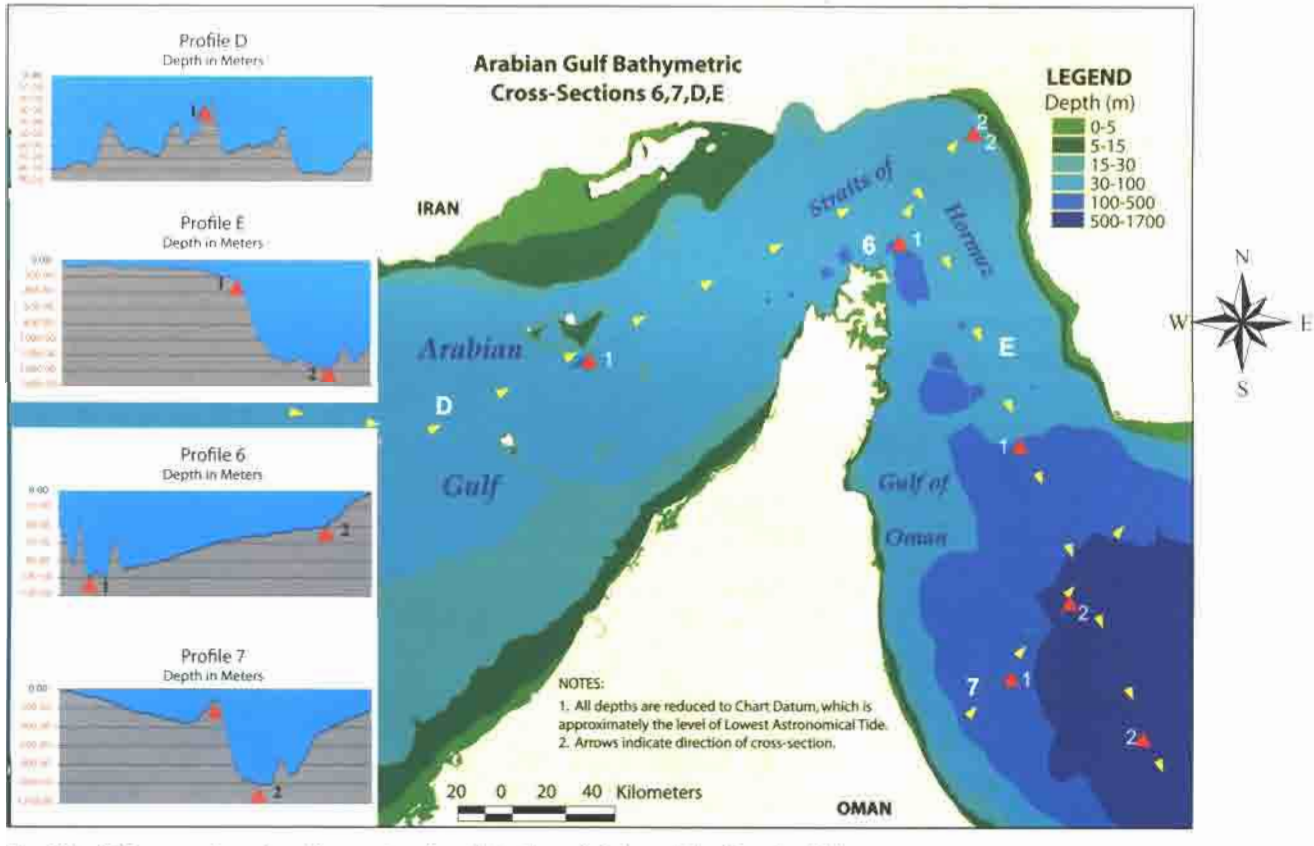


Fig. 22. GIS map showing the water depth in the vicinity of the Strait of Hormuz.

Privette (1959) estimated the evaporation rate for the Gulf to vary between 0.2 and 0.6 g/cm^2/d. Fresh water inflow (Fig. 23) represents only 1.3% to 28% of the water loss to evaporation. Mean surface water temperature of the Gulf ranges from 15.5 in the winter to 33 °C in the summer.

The Arabian Gulf is biologically rich, and its waters include very productive fishing grounds. It has an extensively developed fishing industry based on a variety of finfish (e.g., hamoor, *Epinephelus coioides*; nakroor, *Pomadasys kaakan*; hamra, *Lutjanus malabaricus*; fersh, *Plectorhinchus cinctus*; newaiby, *Otolithes ruber*; sobaity, *Sparidentex hasta*; shaem, *Acanthopagrus latus*; zobaidy, *Pampus argenteus*; safi, *Siganus canaliculatus*, and others), penaeid shrimp (mainly, *Penaeus semisulcatus*) and pearl oysters (mainly, *Pinctada radiata*). The reason for the relatively high commercial productivity of the Gulf waters could lie in the peculiarities of oceanographic conditions and the distribution of the zones of high biological productivity, mainly in the coastal regions.



Fig. 23. Map showing some of the rivers discharging into the Arabian Gulf.

Oceanographic studies of importance that are lacking for the Gulf include time-series measurements. Mapping of space over time for various time-dependent phenomena, ranging from the micro-scale through the meso-scale, are absent. Other studies of interest to oceanographers are either absent or only superficially known. These include the dynamics of the marine system, stratification and the thermocline structure of the water column, processes of mixing, micro-structure of the sea, origin and dynamics of eddies, marine food chains, plankton dynamics, and air-sea interactions. Moreover, Shatt Al-Arab discharge rates into the northern Arabian Gulf have not been available to the scientific community for the past two decades.

General Circulation Pattern of the Arabian Gulf

Our knowledge of the general Gulf circulation is derived from three surveys conducted to map the water masses (Emery, 1956; Brewer and Dryssen, 1985; Reynolds, 1993). A slow, counterclockwise circulation has been described in the Gulf (Hunter, 1982). Much of the circulation observed in the Gulf is due to less saline (lighter) water flowing on the surface through the Strait, becoming more saline (denser) through evaporation, and flowing back through the Strait into the Arabian Sea, below the less dense inflowing water. Therefore, an outflow of deeper high salinity water at the Strait of Hormuz is compensated by an inflow of less saline surface waters from the Arabian Sea and Gulf of Oman into

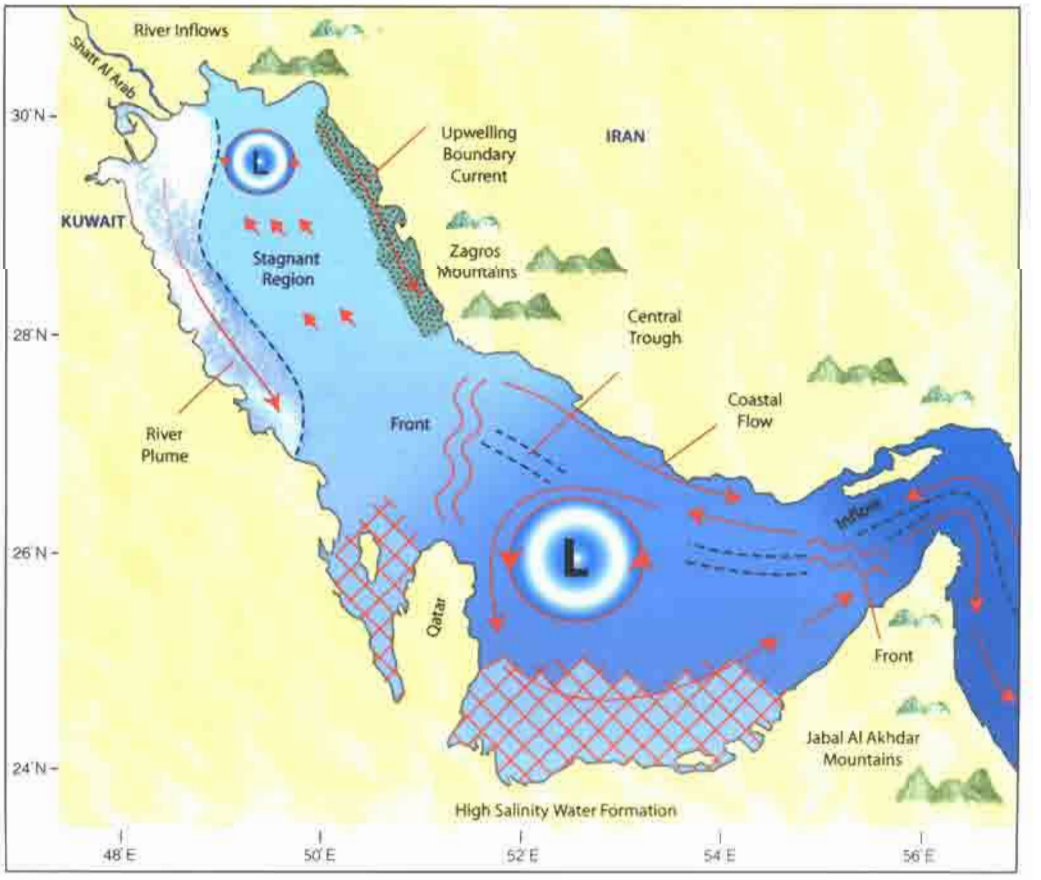


Fig. 24. Circulation pattern in the Gulf (after Reynolds, 1993).

the Arabian Gulf. There are no sills in the Arabian Gulf to limit the exchanges with Gulf of Oman waters. The exchange through the Straits is higher during winter.

In general, there are two low energy cyclonic gyres (anti-clockwise) in the Gulf (Fig. 24). The main circulation pattern is density-dominated in the central and southern Gulf, and the other one is the wind-dominated regime in the NW Gulf. The circulation pattern varies with the seasons. The prevailing southeastward winds drive coastal upwelling on the Iranian side and downwelling on the Arabian side.

Shatt Al-Arab River

Fresh water enters the Gulf in the north by way of the Shatt Al-Arab River (discharge estimated at about 1000 m^3/s by Reynolds, 2002), which is comprised of the waters of the Tigris, Euphrates and Karun Rivers (Fig. 25). The length of the Shatt Al-Arab is about 128 km, and the average width is approximately 500 m. Its depth downstream of Basrah varies between 8 and 15 m (Al-Ramadhan and Pastour, 1987). It flows along a wide valley in a southerly direction (downstream of Al-Qurnah) and discharges into the Arabian Gulf. Peak flow usually occurs in the springtime during the period of March-June, with maximum discharge occurring in May. Seasonal fresh water supply from the Shatt Al-Arab appears to have local effects on the Gulf marine environment, especially the northern Gulf areas, including Kuwait's waters. Moreover, Shatt Al-Arab runoff in the northwest of the Arabian Gulf contributes to the cyclonic circulation (counterclockwise).



Fig. 25. The Mesopotamian Marshlands. Source: Adapted from UNEP, 2001 : Demise of an Ecosystem. Early Warning and Assessment Technical Report (UNEP/DEWA/TR.01-3). United Nations Environment Program, Nairobi, Kenya.

The Shatt Al-Arab is influenced by the tidal pattern in the Arabian Gulf, where the tidal range along the shores is between 2 and 3 m (Al-Ramadhan and Pastour, 1987). Differences in mean surface salinity between ebb and flood tides are greatest at the mouth of the estuary leading to the Arabian Gulf (14.8 psu), and least north of the mouth (2.5 psu) (Mohammad, 1965).

The Shatt Al-Arab is the principal fluvial input to the Arabian Gulf, but estimates of annual discharge vary. Hartmann et al. (1971) and Grasshoff (1976) estimated annual discharge to vary from 5 to 100 X 10^9 m^3 (160 to 3,200 m^2 /s). Hadi et al. (1984) reported that the Shatt Al-Arab estuary pours about 2 x 10^{10} m^3 nutrient-rich water into the Arabian Gulf each year. The Tigris and Euphrates Rivers together provide an annual average of 708 m^3/s, and the Karun adds 748 m^3/s (Reynolds, 1993). Thus, the total average outflow of the Shatt Al-Arab is 1456 m^3/s. Kolars (1992) reported that the combined natural flow of the Shatt Al-Arab averages about 81.9 billion m^3 per year; however, the discharge volume varies due to removals and diversions, as well as seasonal and multi-annual variations.

The waters of the Shatt Al-Arab River are rich in nutrients (Talling, 1980) and particulate organic matter; therefore, the Shatt Al-Arab discharge is especially important for productivity of the northwestern Gulf (Abaychi et al., 1988). The Shatt Al-Arab waters contain 0.18 to 0.70 µg-at/l of phosphate, 26.12 to 52.39 µg-at/l of nitrate, and 0.53 to 0.70 µg-at/l of nitrite. These waters have an average suspended matter load of 125 mg/l (Hartmann et al., 1971).



View from the west bank of the Shatt Al-Arab off Basrah in 1984 (photo by Dr. James Bishop).

Within the basins of the Euphrates, Tigris and Karun Rivers, the mean rainfall varies widely; many areas south and west of Baghdad receive only 12.5 cm, whereas the higher mountains have 175 cm or more (Cressey, 1958). Following a winter of heavy snow in the mountains and coinciding with a period of rapid snow-melt, the resulting stream flow reaches peak records. The three tributaries of the Shatt Al-Arab experience low summer flow due to the almost complete lack of rainfall in their basins. With the arrival of winter rains, the flow increases, but the maximum floods usually occur in the spring due to a combination of heavy rain and snow melt (Cressey, 1958). The average annual rainfall is less than 20 cm, most of which falls between November and March (Shalash, 1966). Surface water salinity varies from 5 psu near the river to 39 psu in the Gulf (Darmoin and Lindqvist, 1988).

The Shatt Al-Arab River, as well as the nearby marshes most of which have been drained, served as an important habitat for some of the commercially important fish and shrimp species. For example, *Metapenaeus affinis*, the commercial shrimp of the Arabian Gulf, migrated to the oligohaline brackish waters of these areas in the beginning of the summer months (June) and returned to the sea during the winter months (December, January and February) (Ali and Al-Bazi, 1987). Ali and Al-Bazi (1987) found that smaller-sized shrimps inhabited the shallow creeks in the Shatt Al-Arab region, whereas larger-sized shrimps were found in the marshes.

Khor Al-Zubair

The Khor Al-Zubair, situated southwest of Basrah, used to be one of the many lagoonal, semi-landlocked tongues of the Arabian Gulf, extending from the Khor Abdullah northward, in a NNW-SSE direction, in southern Iraq (Al-Mussawy and Basi, 1993). The lower boundary of the Khor Al-Zubair is located near Warbah Island about 8 km southeast of Umm Qasr. It joins the Arabian Gulf via Khor Abdullah (Afaj and Elewe, 1989), and it connects to Khor Al-Sabbiya, a river-like channel separating the Sabbiya Peninsula from Bubiyan Island (Dames and Moore, 1983), leading to the northern Arabian Gulf. The total length of Khor Al-Zubair is about 40 km from the upper reaches to the lower boundary at the Khor Sakaa (Afaj and Elewe, 1989; Al-Ramadhan, 1987). It used to be a typical marine system (Ali and Hussain, 1990).

In 1983, the northern tail of Khor Al-Zubair was connected through an artificial canal called the Shatt Al-Basrah (Fig. 25) to the Euphrates River after its emergence from Hor Al-Hammar Lake (the marsh area to the north) (Al-Ramadhan, 1987), changing the Khor Al-Zubair from a typical marine system or negative estuary (i.e., evaporation exceeded the fresh water inflow plus precipitation) to a positive estuarine habitat (Al-Ramadhan, 1987; Ali and Hussain, 1990). The length of Shatt

Al-Basrah is about 37 km. The fresh water discharge from the Euphrates River is controlled by a dam built at a distance of 22 km from the entrance of the channel (15 km from the upper reaches of the Khor Al-Zubair). North of the control dam, the mean depth of the channel is about 4.5 m, whereas, south of the dam, the mean depth is about 7.5 m (Al-Ramadhan, 1987).

The input of fresh water from the Euphrates River through the Shatt Al-Basrah canal to the Khor Al-Zubair has had a considerable effect on the character of the Khor Al-Zubair's water and, consequently, on the physical, chemical and biological aspects of its environment (Al-Mussawy and Basi, 1993). Before the opening of this channel, salinity was as high as 47 psu in the summer months (Emery and Stevenson, 1957). After the opening of the Shatt Al-Basrah channel (in 1983), the environment of the Khor Al-Zubair completely changed, and a longitudinal salinity gradient became well developed (Al-Ramadhan, 1987).

Results of a study conducted between July 1983 and June 1984 near the Khor Al-Zubair in the northwestern Arabian Gulf (Ali and Hussain, 1990) showed that salinity values were more stable throughout the year, with the exception of February when salinity declined sharply. The salinity of the Khor Al-Zubair ranges from 3 to 6 psu in its upper reaches, and from 38 to 40 psu in its lower reaches (Afaj and Elewe, 1989). Fresh water input also plays an important role in the hydrodynamic mixing of the Khor Al-Zubair (Al-Mussawy and Basi, 1993). The Khor Al-Zubair represents a channel of interaction between fresh water discharge of the Shatt Al-Basrah and the saline water of the Arabian Gulf, with its relatively high semi-diurnal tide and wave action (Al-Mussawy and Basi, 1993). The nature of the tide and its phases were found to have a great impact on the settling velocity of particles and, consequently, on the concentration and type of suspended matter in the water (Greoen, 1967; Pejrup, 1988).

The overall richness of fish assemblages in the Khor Al-Zubair underlines the importance of the area as a nursery ground for several local species. Some of the most important commercial species are *Pampus argenteus, Pomadasys argenteus, Otolithes ruber, Acanthopagrus latus, Acanthopagrus cuvieri* and *Epinephelus coioides,* with the peak spawning period occurring in the spring (Hussain and Abdullah, 1977; Hussain et al., 1981; Abu-Hakima, 1984).

The Mesopotamian Marshlands of the Tigris-Euphrates Delta

The Euphrates River divides into two branches at its lower reach in Iraq (Saad, 1982). One branch previously joined the Tigris River at the town of Qurnah, forming the Shatt Al-Arab. The other branch traversed the Hor Al-Hammar, previously a large marsh enriched with aquatic plants, and then joined the Shatt Al-Arab at Sindibad Island. The water of the Shatt Al-Arab may reach the Hor Al-Hammar during high tide, and the brackish water from the Hor Al-Hammar may enter into the Shatt Al-Arab during ebb tide. The levels of the Tigris and Euphrates rise in the spring (following the melting of snow in Turkey), and this increases the level of the Shatt Al-Arab during this season (Saad, 1982).

The Shatt Al-Arab's waters are relatively transparent before they join with the turbid waters of the Karun River. This is attributable to the slow circulation of the Tigris and Euphrates Rivers through the extensive marshes, which acted as silt traps in the southern parts of Iraq (Mohammad, 1965) before their drainage.

Marsh Arabs, before their displacement due to marsh drainage, lived in reed houses on artificial islands amid the waters of the marshes. The Marsh Arabs relied on floods every winter and spring to replenish the marshes (Pearce,1993).

The marshes provided important habitats for a wide range of fish species, including migratory species of commercial importance beyond the borders of Iraq. Seasonal migrations of the commercial penaeid shrimp *Metapenaeus affinis* are believed to have taken place between the Gulf and nursery grounds in the marshes of Iraq. Hor Al-Hammar Lake served as one such nursery ground. This shrimp is of significant economic importance to artisanal fishermen along the coasts of the northern Gulf, particularly, in Kuwait. In some years, this species accounted for over 40% of the total Kuwaiti landing (J. Bishop, 2003, personal communication). The pomfret *Pampus argenteus* depends on estuarine areas for nursery habitats, and the anadromous suboor *(Tenualosa ilisha)* is also dependent on Iraq's marshes and river system for breeding/spawning.



Marsh Arab poling high bowed "Mashuf" through Phragmites marshes (photo by Dr. James Bishop, January 1984).

Iraq has prevented at least two-thirds of the river water from reaching the marshes, which has had disastrous ecological, social and human consequences for the region. Iraq has systematically drained vast stretches of marshlands where the Tigris and Euphrates Rivers merge into the Shatt Al-Arab River. Loss of marsh habitat, alteration of water flow and quality in the rivers, and reduced discharges to the Gulf are likely to impact the fisheries of the northern Gulf region, with potentially serious economic results. The progressive changes to the hydrological regime of the marshes has resulted in the loss of habitat for important fish species and in the demise of an essential fishery resource.

International efforts to rehabilitate the marshes of southern Iraq are under way.



Marsh Arabs in the Hor Al-Hammar marshes seining for fish and shrimp (photo by Dr. James Bishop, 1989).



*Marsh Arab dwelling of **Phragmites** reeds with water buffalos (photo by Dr. James Bishop, 1986).*

The Third River

Iraq completed its 565 km main outfall drainage scheme (MODS), or the Third River Project, renamed the Saddam River, in December 1992 (Pearce, 1993). The Third River (Fig. 25) has a total discharge of 210 m^3/s, and functions as a main outfall drain, collecting drainage waters of more than 1.5 million square kilometers of salt-encrusted fields, which might increase Iraq's crop production by up to 50% (Pearce, 1993). The Third River's purpose is to rid farmland between the Tigris and Euphrates Rivers of its chronic salinity problem by diverting the flow of the Euphrates into the canal, cutting the flow of fresh water to the southern marshlands. Almost the entire flow of the Euphrates into the Al-Hammar marsh has been diverted into the Third River, which has been connected to the sea (Pearce, 1993). This river now carries the floodwaters that once fed the marshes, as well as wastewater, down to the Arabian Gulf through the Khor Al-Zubair and downward to Khor Al-Sabbiya.

Recent River-Related Developments

The northern Gulf ecosystem is experiencing a combined impact of massive marsh drainage work in southern Iraq, which started in early 1990 as well as upstream damming of rivers by Turkey and Iran (Karkheh dam). Iraq has drained more than 60% of the 15,540 km^2 world-famous Mesopotamian Marshlands, which have disappeared since the first Gulf War (Ryan, 1994). These marshes serve as a biodiversity centre of global importance. Iraq's marsh drainage scheme, known as

the "Three Rivers Project", involved straightening parts of the Tigris and Euphrates and construction of canals, all of which discharge water quickly through the estuary to the Arabian Gulf. With marshes intact, the residence time of river water in the estuary region is relatively long. Although estimates exist of total basin flows (Reynolds, 1993), there is no estimate of the average residence time for a parcel of water from the upper marsh system to the mouth of the Shatt al-Arab. The residence time is important not only because of its effect on sustaining the marsh ecosystem, but also of its major role in controlling the amount of nutrients, organic matter, and sediments that the river discharges into the northern Arabian Gulf.

Turkey's Southeast Anatolia Project is one of the world's biggest engineering projects to harness the flows of both Tigris and Euphrates rivers, which will cover an area of 27,500 km^2 roughly 1.7 times larger than Kuwait. The purpose of this project is to provide water for irrigation of 1.7 million hectares of agricultural lands and generate 27.3 billion kilowatt-hours of electricity. No fewer than 22 dams, 19 of which will generate electricity, at an estimated cost of U.S. $ 20-25 billion will impound waters of the Tigris and Euphrates Rivers when the project is completed by the year 2010. With the completion of the Ataturk Dam on the Euphrates River, flow rates have dropped to alarming volumes causing concern in both Syria and Iraq (Gurdilek, 1992). As more dams are completed, evaporation from the impoundments increases and drawdown for irrigation will greatly diminish flow rates downstream. As a consequence, discharge rates of the Shatt al-Arab will be negligible during the drier periods of the year. Such changes in the water budget of the northern Gulf will have profound and irreversible effects on Kuwait's fisheries that depend directly and indirectly on low salinity water.

Primary Productvity of the Arabian Gulf

The Arabian Gulf, though productive, lacks systematic studies on primary productivity and energy flow. In general, and based on the results of limited studies, there seems to be a north to south gradient in the biomass and primary productivity of the Arabian Gulf. Jones et al. (2002) provided a concise summary of the primary productivity of the Arabian Gulf, which is presented below.

Factors Affecting Primary Productivity in the Arabian Gulf. The enhanced plankton biomass and the elevated production of coastal waters reflect the combined effects of geophysical, chemical and biological processes. Of the many environmental factors that influence primary production, the light field (to support photosynthesis), and the rate of nutrient input to the primary producers are the most regulatory factors. Nutrient concentrations in the coastal waters of Kuwait are high, and the mixed layer in the coastal zone extends to the bottom (Michel et al., 1982). Relatively few studies have examined these factors in relation to the distribution and magnitude of primary productivity in the Arabian Gulf (Grice and Gibson, 1978; Grasshoff, 1976; Jacob et al., 1979; Al-Yamani, 1989).

Photosynthesis can take place for a time if a plant cell is provided only with light, water and carbon dioxide, but growth and hence production is dependent on the availability of various mineral nutrients (Jacob and Muzaini, 1990). At least 18 minerals and various organic growth factors have been shown to be necessary for phytoplankton growth (Fogg, 1975). For the primary producers of the Arabian Gulf, the water supply and carbon dioxide supply are not limiting. However, other factors such as availability of enough light, dissolved oxygen, nutrients like nitrates, phosphates, silicates and a suitable ambient temperature for metabolic activity are critical parameters for some areas in the Arabian Gulf, e.g., water transparency in the northwestern Gulf (e.g., northern Kuwait's waters including Khor Al-Sabiyah) is low in general.

Phytoplankton Primary Productivity. Studies of phytoplankton stocks and primary production are necessary for fisheries management as well as an early warning of eutrophication. Phytoplankton, the primary producers in the marine environment, represent the basis for studies aimed at understanding the food web dynamics in an ecosystem.

There is a paucity of quantitative and qualitative information on the phytoplankton population pertaining to the Arabian Gulf when compared with the Arabian Sea and other neighbouring seas. A number of studies have been conducted in the Arabian Gulf to estimate primary productivity from total counts of phytoplankton cells, chlorophyll analyses, light and dark bottle techniques and by the radioactive C-14 tracer technique, but most of these studies are confined to specific locations and do not cover the whole year (Jacob and Al-Muzaini, 1990, Al-Yamani et al., 1997b). In addition, difficulties in comparing productivity results from different Gulf waters arise partly (1) because of the different measures of productivity selected by different authors (measurements of mg or g, expressed as m^2 or m^3; and production per day or year) and partly (2) because of problems with experimental conversion factors between, for example, chlorophyll-*a* and carbon (Sheppard, 1992). In general, measurements of weight and time are unified, but volume-area measurements are not.

Huq et al. (1978) reported the primary productivity of the northwestern Arabian Gulf as 161 mg $C/m^3/d$ based on the ordinary light-and-dark bottle oxygen method described by Strickland and Parsons (1972).



Halodule *sea grass beds at low tide.*

Several estimates of average phytoplankton production are available for certain areas in the Arabian Gulf. Measurements of primary production in the Shatt Al-Arab estuary during 28 February and 3 March 1985 ranged between 5.44 and 10.3 µg C/l/h (Al-Saadi et al., 1989). Photosynthetic rates during November in the eastern canal of the Shatt Al-Arab ranged from 18.5 to 52.3 µg C/l/h (Hadi et al., 1989). In the western canals that received sewage they were very high and ranged between 31.5 and 3180.9 µg C/l/h (Hadi et al., 1989).

Jacob et al. (1979, 1980) in their study in Kuwait's waters reported an average primary production value of 0.26 $gC/m^3/d$ from January to March, 1979, but a higher average value of 0.866 $gC/m^3/d$ from March to May, 1978. However, their estimates were computed from total chlorophyll values. Al-Yamani et al. (1997b) reported average primary production rates of 152.89 µgC/l/d with a minimum of 11.40 µgC/l/d and a maximum of 610.00 µgC/l/d using the C-14 method. During a local red tide episode in Kuwait's waters, phytoplankton daily production ranged between 6094 and 6855 µg C/d/l (Subba Rao et al., 1999) in the red tide bloom. Hirawake et al. (1998) reported that the primary production was high in the waters off Iran near the enterance of the Arabian Gulf, while the water off Qatar Peninsula to the United Arab Emirates was less productive.

Some preliminary information is available on the phytoplankton biomass in the Arabian Gulf. The biomass is estimated to be > 4 mg/m^3, while it reaches 15-18.9 mg/m^3 in the northwestern area of the Arabian Gulf (Jamal and Pavlov, 1979; Al-Yamani et al., 1997a, b). Phytoplankton constitutes 60-90% of total biological biomass in areas where plankton biomass is > 500 mg/m^3, and three high plankton biomass areas are identified: (1) northwestern side of the Arabian Gulf, off Kuwait's coast, (2) off Qatar Peninsula in the central side of the Arabian Gulf, and (3) Strait of Hormuz along the southeastern side of the Arabian Gulf (Jamal et al., 1979). Chlorophyll-*a* concentrations for Kuwait's waters have been reported by Jacob et al. (1979, 1980); and Al-Yamani et al. (1997a,b). Al-Saddi et al. (1976) in their study of the northwestern part of the Arabian Gulf, found higher chlorophyll-*a* concentrations near Shatt al-Arab outflow. Seasonal variations in phytoplankton biomass were studied for the nothwestern side of the Arabian Gulf during 1971-1972, where the lowest phytoplankton biomass was found in October and November of 1971 (0.17 mg/m^3), and highest in January 1972 (4.05 mg/m^3) (Al-Saadi et al. 1976). In the study area off the central coast of Iran in 1976, it was concluded that this area was impoverished in terms of phytoplankton populations (IRI, 1988).

A review of the phytoplankton of the Arabian Gulf is provided by Dorgham et al., 1987, who also reported on species composition and biomass of the phytoplankton in waters along the northwestern part of the Arabian Gulf off Kuwaiti, Saudi and Qatari shores in the autumn of 1984. Al-Kaisi (1976), indicated that most of the species reported in the Indian Ocean by Krey (1973) and Subrahmanyan and Sharma (1960) for the Gulf of Oman and the Arabian Sea were commonly found in the Arabian Gulf waters, possibly due to current transport. For a check list of phytoplankton species for the Arabain Gulf, refer to Dorgham et al., 1987; Grice and Gibson (1978); and Al-Kaisi (1976), and for localized areas refer to Dorgham and Muftah (1986) for Qatari waters; Jacob and Al-Muzaini (1990), Al-Yamani et al. (1997b) and Subba Rao and Al-Yamani (1998) for Kuwait's waters; Basson et al. (1977) and Jones et al. (1978) for Saudi Arabian waters; Kell and Saad (1975) for Shatt Al-Arab region; and Hulburt et al. (1981) for Bushehr in Iranian waters.

Intertidal Productivity, Microbial Mats, Mangroves, Salt Marshes, Seagrass Beds. The intertidal zone of tropical coasts is generally rich covered by a large number of seaweeds and seagrasses which form distinct zones (De Clerck and Coppejans, 1994). However, the Gulf shoreline of Saudi Arabia is almost devoid of algae and seagrasses (except in Tarut Bay) due to the extreme annual fluctuations in temperature and salinity (John et al., 1990; Basson et al., 1977). Studies of intertidal vegetation, microbial mats, mangroves and salt marsh vegetation, and their trophic relationships in the Arabian Gulf are very few and productivity estimates for most areas in the Gulf remain unknown.

Intertidal Productivity. Literathy et al. (1988) reported the primary productivity of the interidal area of Kuwait during low and high tides based on the C-14 method. For Kuwait, during high water, the inter-tidal productivity was almost uniform but higher inside Kuwait Bay where the nutrient input was most likely higher. Literathy et al. (1988) conducted a study on the primary productivity of the coastal waters of Kuwait using C-14 tracer technique during 1983-1984. They reported primary productivity range from 0.2-1.6 mg C/m^3/h. Primary productivity values of the coastal waters (intertidal zone) of Kuwait during December, 1987 ranged from 2.1-23.1 mgC/m^3/h (i.e., 25.2-277.2 mgC/m^3/d) at low water, and 4.5-7.9 mgC/m^3/h (i.e., 54-94.8 mgC/m^3/d) at high water level. There were different levels of primary production in the shoreline samples at low and high tide. Both stimulation and inhibition were observed at low water in the areas directly affected by sewage discharge. Inhibition (possibly by copper or other metals) was particularly high at one of the locations, where low productivity was measured despite high nutrient concentration. Productivity of Kuwait's waters might be *higher than the rest of the Arabian Gulf due to significantly higher nutrient levels, and, particularly in Kuwait Bay.* Published interidal primary productivity estimates are lacking for other areas of the Arabian Gulf.

Microbial (Algal) Mats. Algal mats are stratified communities consisting of several algal species, mainly cyanobacteria, which are collectively living in a balance, with optimum growth based on light and nutrients (Al-Thukair and Al-Hinai, 1993). The importance of algal mats is only recently being appreciated in the Arabian Gulf.

Before the 1991 Gulf War extensive blue-green algal mats covered the intertidal zone of the western Gulf, most of which were severly affected by the subsequent oil spill. By mid-1992, areas where the tar layer had been covered by sediment were recolonized (Hoffmann, 1994). Different mat morphologies (folded, pinnacle, flat or polygonal) are found to be related to their species composition and to the environmental factors in which they grew (e.g., tidal regime, drainage, sedimentation rates, degree of exposure to wave action, etc.) (Hoffmann, 1994). The most common taxa in these mats are filamentous blue-green algae/bacteria belonging to the genera *Lyngbya, Microcoleus, Phromidium* and *Schizothrix*. In some salt-marshes, the heterocystous genus *Scytonema* is of importance (Hoffmann, 1994).

Kendall et al., 1966, and 1968 reported on the algal mats in the waters of the United Arab Emirates, but no productivity

estimates were given. Kinsman and Park, 1976 described the algal belt in the southern coastal waters of the Arabian Gulf. Al-Thukair and Al-Hinai (1993) identified the existence sites of algal mats along the coast of Saudi Arabia and mapped their extent by using satellite imageries. Species composition of various algal mats in Saudi Arabia and Kuwait are in progress. No productivity values are reported for the algal mats of the Arabian Gulf, except for Kuwait Bay. Annual gross benthic microalgal production for Kuwait Bay was measured to be 190 gC $m^{-2} Y^{-1}$ (Al-Zaidan, 2002).

Mangroves. Mangroves are among the most productive ecosystems in the world, and therefore, play an important role in the overall productivity of the marine ecosystem. However, primary productivity of mangroves varies enormously at both the local and regional scale. Salinity, and climate factors such as solar irradiance, cloudiness and the ratio of precipitation to evapo-transpiration together with nutrient availability are key factors regulating mangrove growth and productivity (Al-Muharami, 1994). Net primary productivity in mangrove ecosystems has been measured to be in the range from 300 to 2000 gC/m^2/y (Mann, 1982). Aside from high primary productivity, it is believed that the natural functioning of mangrove ecosystems supports high secondary productivity in the form of estuarine and coastal fisheries. For example, MacNae (1974) found that the extent and health of coastal mangrove wetlands are positively correlated with shrimp (*Penaeus* spp.) yield in adjacent waters. Mangroves are important as nursery grounds for juvenile shrimps, and must be studied in depth.

In the Arabian Gulf, mangroves occur along the upper intertidal zone in certain embayments. Mangrove communities are found all along the eastern coast (off Iran) of the Gulf (Chapman, 1960, 1970, 1974). On the western Gulf, mangroves are present in Saudi Arabia, Bahrain, Qatar and Oman (Jacob and Al-Muzaini, 1990). However, they are absent in Iraq and Kuwait. *Avicennia marina* is the most important species of the mangroves in the Gulf. Basson et al. (1977) reported the occurrence of the black mangroves *A. marina* in Tarut Island on the western coast of the Gulf. Seaward of the mangrove belt, an algal mat is usually present (Basson et al., 1977). Also, *A. marina* is in general associated with *Arthrocnemum macrostachyum* and *Salicornia europaea* (Böer, 1994). Development has destroyed major stands of mangrove habitat, particularly in Saudi Arabia. Saenger (1993) noted a relationship between decreased shrimp landings in Saudi Arabia and intense landfilling in Tarut Bay, which is characterized by mangroves and a known major nursery ground for *Penaeus semisulcatus*. Mangroves are being replanted in Qatar, and successfully introduced into Kuwait. Primary production rates for the mangroves in the Arabian Gulf need to be studied.

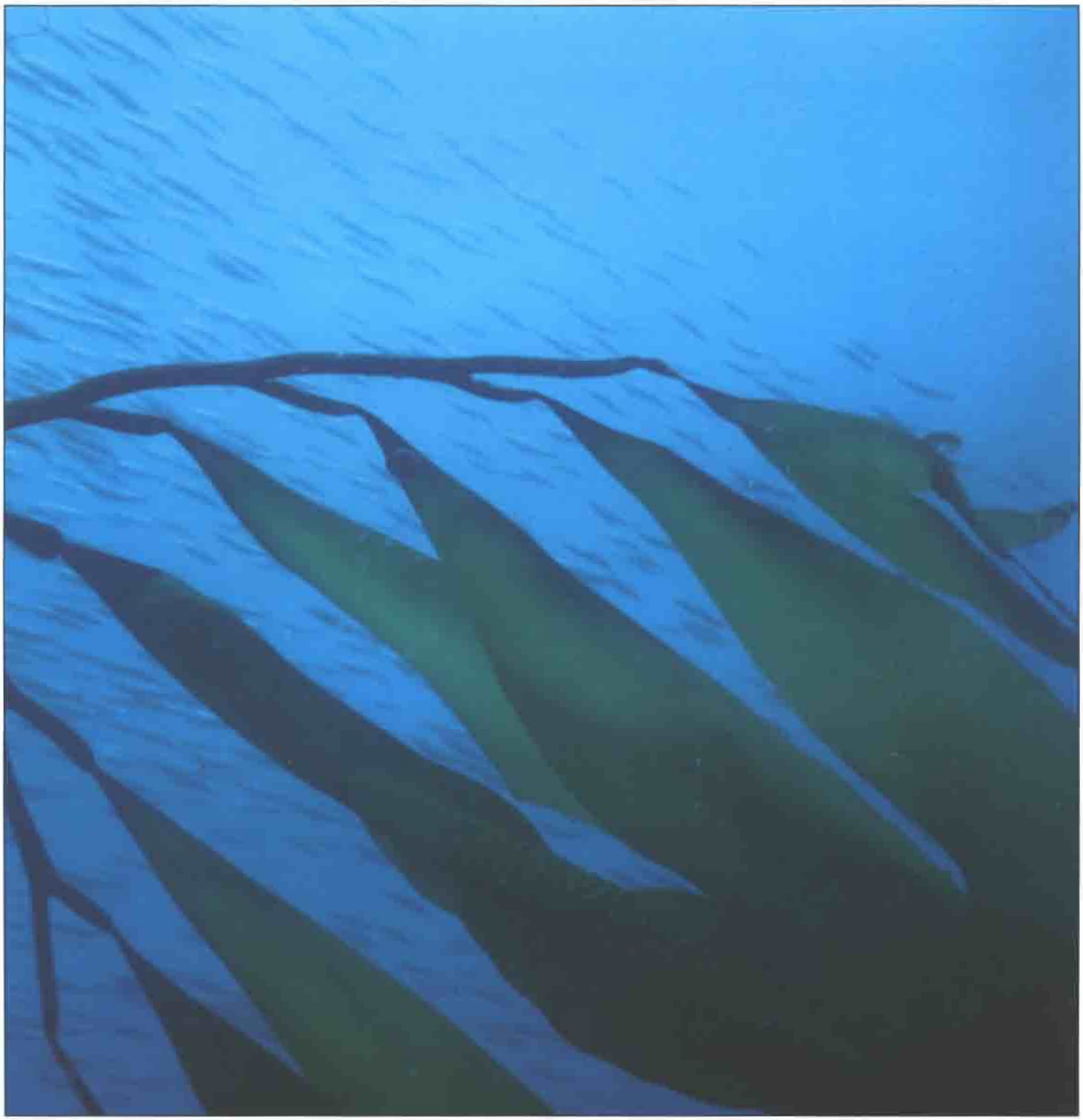
Salt Marshes (Halophytes). Large areas of salt-marshes exist in the western Arabian Gulf. The different salt-marsh types are dominated by *Arthrocnemum macrostachyum, Halocnemon strobilaceum, Halopepils perfoliata, Limonium axillare* and *Salicornia europaea* (Böer, 1994). Kuwait's extensive intertidal areas in Kuwait Bay are characterized by lack of vegetative cover, but certain halophytes are tolerant of the extreme conditions. In certain areas of the extreme upper intertidal zone, stands of *Salicornia* and *Halocnemon* occur (Daoud and Al-Rawi, 1985). These plants are primary producers, but the magnitude of their importance to Kuwait's detrital food chain is not known (Bishop, 1998). Primary productivity estimates for the salt marshes in the Gulf are not studied.

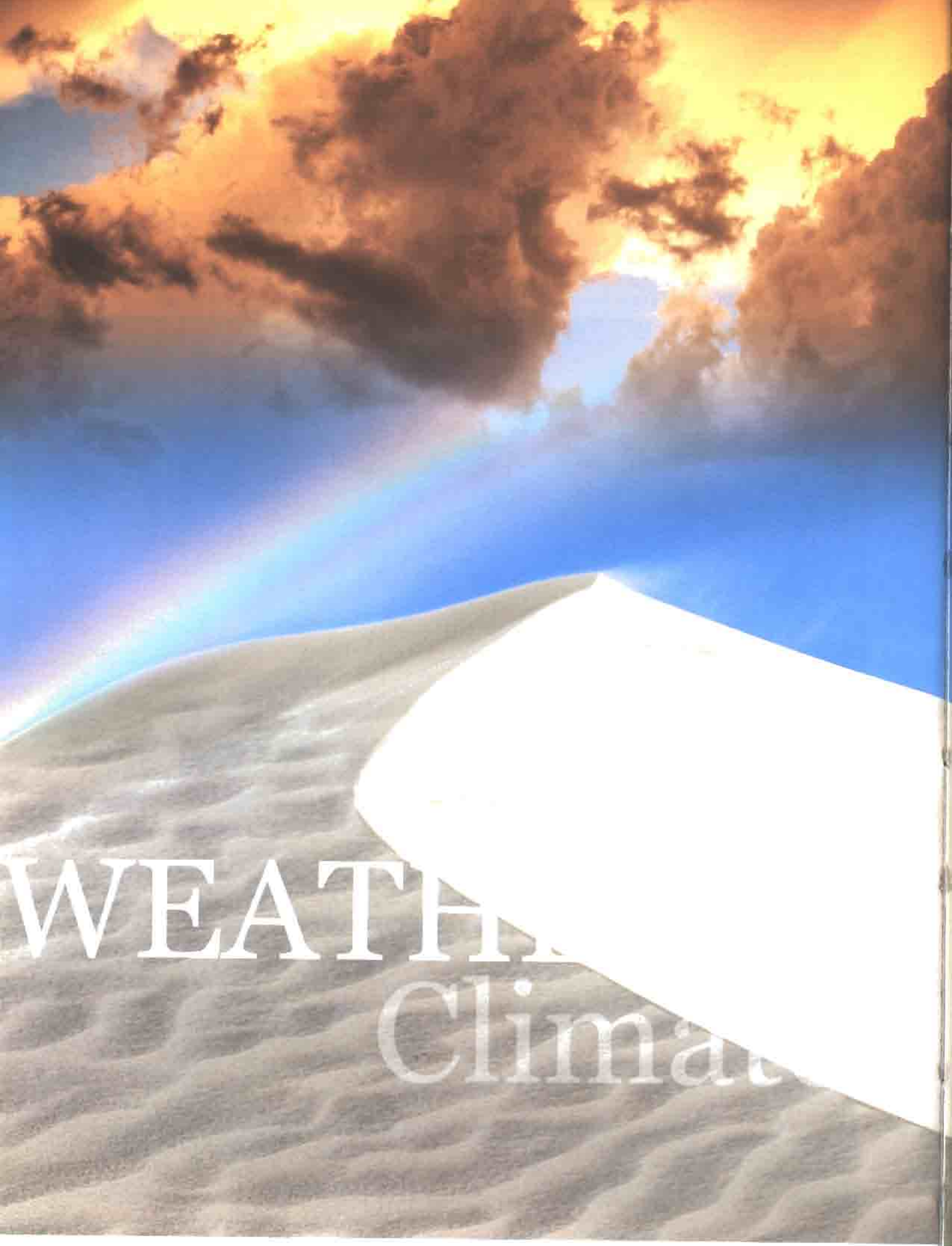
Seagrass Beds. Sea grass forms a major food source for many important marine animals, and provides a habitat for many subadult marine species, e.g., the commercial shrimp *Penaeus semisulcatus*. Seagrasses play a major role in stabilizing bottom sediments (Basson et al., 1977). The Arabian Gulf sea grass species, seasonal cycles and growth rates need to be studied thoroughly.

Sea-grasses in the Arabian Gulf are characterized by high biological productivity. Three species are represented in the Gulf: *Halodule univervis, Halophila ovalis* and *Halophila stipulata*. They are found along the Saudi Arabian coast, with extensive beds in the Tarut Bay area (Basson et al., 1977), and in other areas of the Arabian Gulf (Chapman, 1960, 1970, 1974). *Syringodium isoetifolium* exists in Bahrain's deep waters (Khamdan and Al-Shehabi, 1992). Outside the Arabian Gulf, species such as *Syringodium isoetifolium* and *Cymodocea serrulata* are present in the waters of Oman (Jacob and Al-Muzaini, 1990).

H. ovalis seagrass is the major contributor to seagrass productivity around Bahrain Island (Khamdan and Al-Shehabi, 1992). The same is true for the seagrass in the western Gulf for Saudi Arabia (Basson et al., 1977). Basson et al. (1977) reported a biomass value of 128 g dry weight (650 g wet weight) for seagrass leaves per square meter in Tarut Bay, and 98-608 g dry weight for leaves per square meter for other parts of the world. Price and Coles (1992) measured seagrass biomass for the entire Saudi Arabian shoreline of the Arabian Gulf, and reported mean values ranging from 53-235 g/m^2 (dry weight). Their study indicated that seagrass biomass decreased with depth due to limitation by light. Khamdan and Al-Shehabi (1992) reported seagrass biomass values of 0.0007-0.0165 g ash weight/m^2 for Bahrain.

Macroalage. The marine macroalgal flora from the Arabain Gulf are not well known (Jacob and Al-Muzaini, 1990; Al-Muzaini and Jacob, 1996). Several species of the subtidal macroalgae *Sargassum* occur in Kuwait's waters, *S. angustifolium*, *S. binderi*, *S. boveamum*, and *S. boveanum* var. *aterrimum*. These species occur in Kuwait Bay, between Ras Ajouzah and Ras Al-Ardh. *Sargassum* occurs in a discontinuous strip paralleling the coast in waters less than 5 m deep from Kuwait Bay to the border of Saudi Arabia (Bishop et al., 1995). *Sargassum* reaches its maximum growth in the spring, after which it breaks free of its holdfasts as water temperature increases above 25°C. Nutrients from the flood waters of Shatt Al-Arab in late winter and early spring, and cool water temperatures are favourable for growth and prolong *Sargassum*'s benthic phase, respectively (Bishop, 1998). Other sub-tidal benthic macroalgae such as *Ulva*, *Enteromorpha*, *Chaetomorpha* and *Cladophora* are found in southern Kuwait Bay and have peaks in February and March, but disappear by April or May (Wright, 1989). No primary productivity estimates are known for the macroalgae of the Arabian Gulf.




WEATH
Climat



MARINE METEOROLOGY, KUWAIT'S WEATHER AND CLIMATE

The Wonders of Weather

Weather plays an important role in our daily lives such as influencing what we wear, and affects most of our outdoor activities, such as sailing, fishing, swimming, diving, traveling and gardening. The weather and changing skies are with us every day. Weather is concerned with the changes occurring in the air around us, differences in the air temperature and the air's content of water vapor. The water-vapor content, known as relative humidity, varies considerably, depending on the temperature. Water-vapor content is less at low temperatures and increases as temperature rises (maximum 100 percent relative humidity).

Weather is the state of the atmosphere at a particular time and place. The elements of weather include temperature, humidity, cloudiness, precipitation, wind and pressure. All weather systems have well-defined cycles and structural features and are governed by the laws of heat and motion. These conditions are studied in meteorology.

Atmosphere is a term used for the mixture of gases surrounding any celestial object that has a gravitational field strong enough to prevent the gases from escaping; especially the gaseous envelope of the earth. The principal constituents of the atmosphere of the earth are nitrogen (78 percent) and oxygen (21 percent). The atmospheric gases in the remaining 1 % are argon (0.9 %), carbon dioxide (0.03 %), varying amounts of water vapor and trace amounts of hydrogen, ozone, methane, carbon monoxide, helium, neon, krypton and xenon.

Wind is the flow of air relative to the earth's surface. A wind is named according to the point of the compass from which it blows. Therefore, the wind direction is given as the direction from which the wind is coming. For example:

A wind blowing from the north is a north wind.

WEST or WESTERLY winds are FROM the west, blowing from west to east.

EAST or EASTERLY winds are FROM the east, blowing from east to west.

Winds are produced by differences in atmospheric pressure, which are primarily attributable to differences in temperature. When the temperatures of adjacent regions become unequal, the warmer air tends to rise and flow over the colder, heavier air. Wind is a term used for air in motion, and is usually applied to the natural horizontal motion of the atmosphere.

Current is also a term used for air in motion, but in a vertical, or nearly vertical direction.

Meteorology is the study of the earth's atmosphere, weather and weather forecasting. Everyone's life is affected by the weather.

Weather is different in different parts of the world. For example, in Kuwait, we experience different types of weather such as hot, dry, cold and wet weather at different times of the year. Weather differs from climate.

Climate is the normal kind of weather that a particular region or country experiences over a long period of time, and it includes the averages and variations of all weather elements.

Marine meteorology is the study of weather at sea and along the coasts. It involves studies and prediction of hurricanes, coastal cyclones, storms, sea breeze fronts, and tides. Satellite remote sensing of clouds, winds, ocean roughness, and ocean color plays a key role in meteorological studies. Marine meteorological information are necessary for safe and economic conduct of shipping operations, fishing and other marine activities.

Meteorological Conditions of Kuwait

Kuwait's Weather and Seasons. Kuwait generally has four seasons: winter, spring, summer and autumn. These seasons can be divided into sub-seasons, such as periods of frequent duststorms, frequent thunderstorms, or persistent winds during a given season. Knowledge of these sub-seasons is vital for safe navigation, upon which Kuwait's economy depended until the production of crude oil. Figure 26 displays annual variations of rainfall, duststorms and thunderstorms.

Rainfall in Kuwait has an 11-year cycle, and is divided to three periods, namely, 4 years, 4 years, and 3 years. The first year of each period is rainy, e.g., the year 2000 was a rainy year. Mean rainfall values for the different months are as follows: 6.8 mm in October, 18.3 mm in November, 22.8 mm in December, 25.8 mm in January, 17.8 mm in February, 16.7 mm in March, 14.1 mm in April, 5.2 mm in May, and 0.5 mm in June. The highest rain quantities occur in the winter months of December and January. Rainfall in Kuwait varies spatially and inter-annually. The table below displays the inter-annual variability of rainfall at two cities in Kuwait.

Table of rainfall in two cities in Kuwait showing spatial and inter-annual differences.

Year	Al-Shuwaikh Rainfall (mm/yr)	Al-Ahmadi Rainfall (mm/yr)
1954	336	217
1972	0.5	94

Wind speed and direction vary seasonally and inter-annually. Wind direction is usually northwesterly 43% of the year, increasing to 63% during summer months and decreases to 31% during the spring season. Southeasterly winds occur 19% of the year, with maximum occurrence (27%) during spring, and minimum (9%) during summer (Al-Ajmi and Mustapha, 1998). The table below (Al-Ajmi and Mustapha, 1998) displays wind direction and percentage of their occurrence for the different seasons of winter (December, January, February), spring (March, April and May), Summer (June, July, August, and September) and fall (October and November).

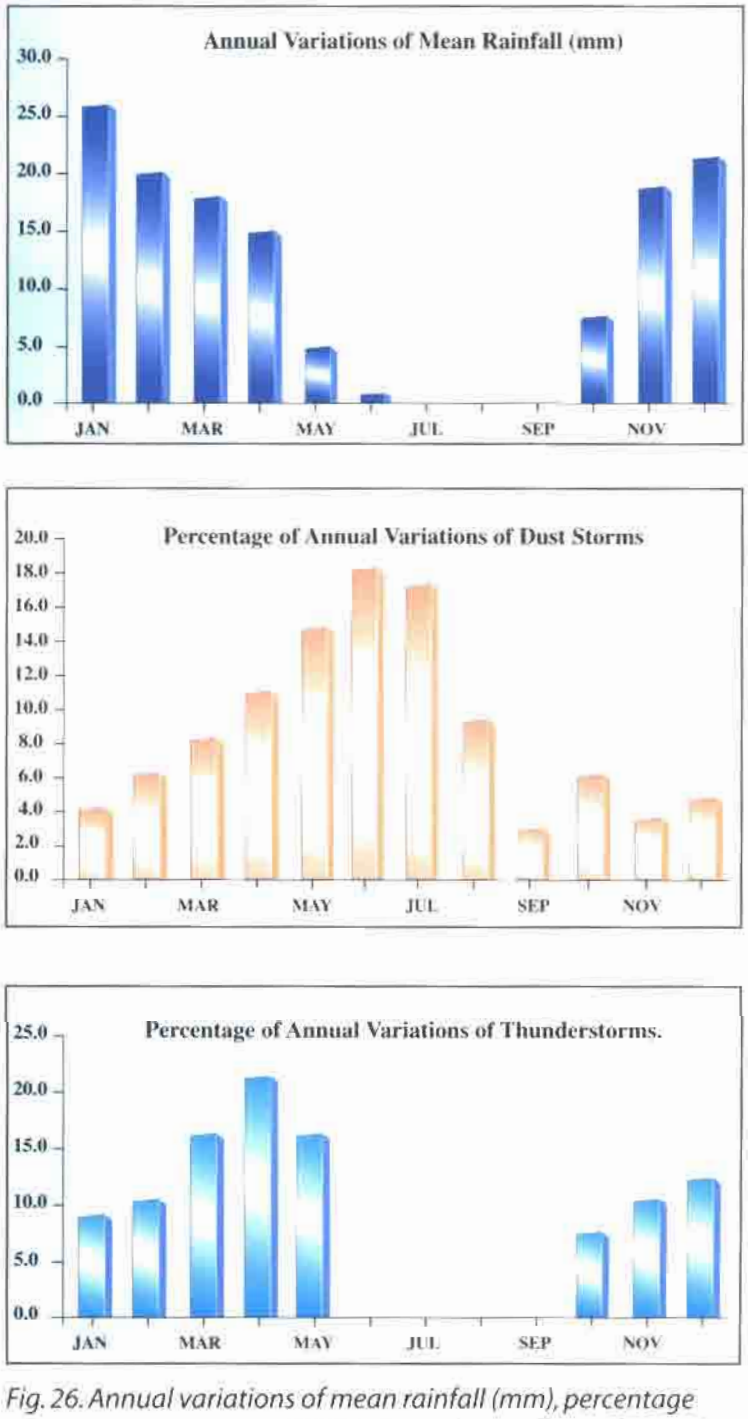


Fig. 26. Annual variations of mean rainfall (mm), percentage of annual variations of duststorms and percentage of annual variations of thunderstorms.

Wind Direction/Percentage Occurrence

Season	NW	NE	SE	SW	Calm	Variable
Winter	42	10	21	9	16	2
Spring	31	17	27	13	10	2
Summer	63	8	9	10	8	2
Fall	38	14	18	12	15	3

The table below displays the wind direction and the highest speed for each month registered at Kuwait International airport for the period of 1962-1986 (Al-Ajmi and Mustapha, 1998).

Month	Wind Direction	Highest Sustained Speed (Knots= nautical miles/hour)
January	SSE	37
February	ESE	37
March	SSE	40
April	SW	45
May	WSW	57
June	NW	39
July	NNW	36
August	NW	37
September	NW	34
October	NW	42
November	ENE	33
December	SW	37

Middleton (1986) reported that the lower Mesopotamian plains have the highest number of dust storm days per year in the region. Dust storms in Kuwait can occur during any month of the year, but are most common between March and August. Of the total 128 dust-storm hours per year, 50% occur during the months of June and July. Unusual and severe dust storms occurred during March and April of 2003, however. Dust storms are characterized by both wind direction and timing. About 80% of dust storms are accompanied by northwesterly winds, and dust storms are most intense during the day in the summer. Conditions are generally more dusty from 10 a.m. until 7 p.m., and less dusty at night and the early morning hours (Al-Ajmi and Mustapha, 1998).

In general, Kuwait has a typical desert climate. Air temperature can dip to 0 °C in winter, and often exceeds 50 °C in the summer. Rainfall is extremely low, with a mean of 128 mm/yr for the period of 1958 till 2002, as compared to annual rainfall in Italy where average annual rainfall exceeds 800 mm/yr or Brazil where it is more than 1100 mm/yr. Most rainfall in Kuwait occurs between October and May, with negligible or no precipitation during the rest of the year. Tables 4a and 4b present the different patterns of local weather and weather-related terminology in Kuwait. In this regard, we would like to mention that the dates provided for some of the climatological phenomena for Kuwait might vary from one climatologist to another and among different sources (Tables 4a and 4b). Also, marine climatologists report dates for a specific phenomenon that might differ from dates reported by an experienced desert dweller. For example, H.R.P. Dickson in his book "The Arab of the Desert" mentioned that Al-Sarayat season extends till 27 May, and that Al-Marba'aniah starts from 23 November and ends in 1 January. Mohammad Al-Asfour and Hussein Al-Asousey, two well-known Kuwaiti navigators in the 20th Century reported in their book "Al-Nateeja Al-Kuwaitiah" that Al-Marba'aniah starts on 5 December and ends on 15 January.

Table 4a. Summary of Local Weather and Weather-Related Terminology in Kuwait

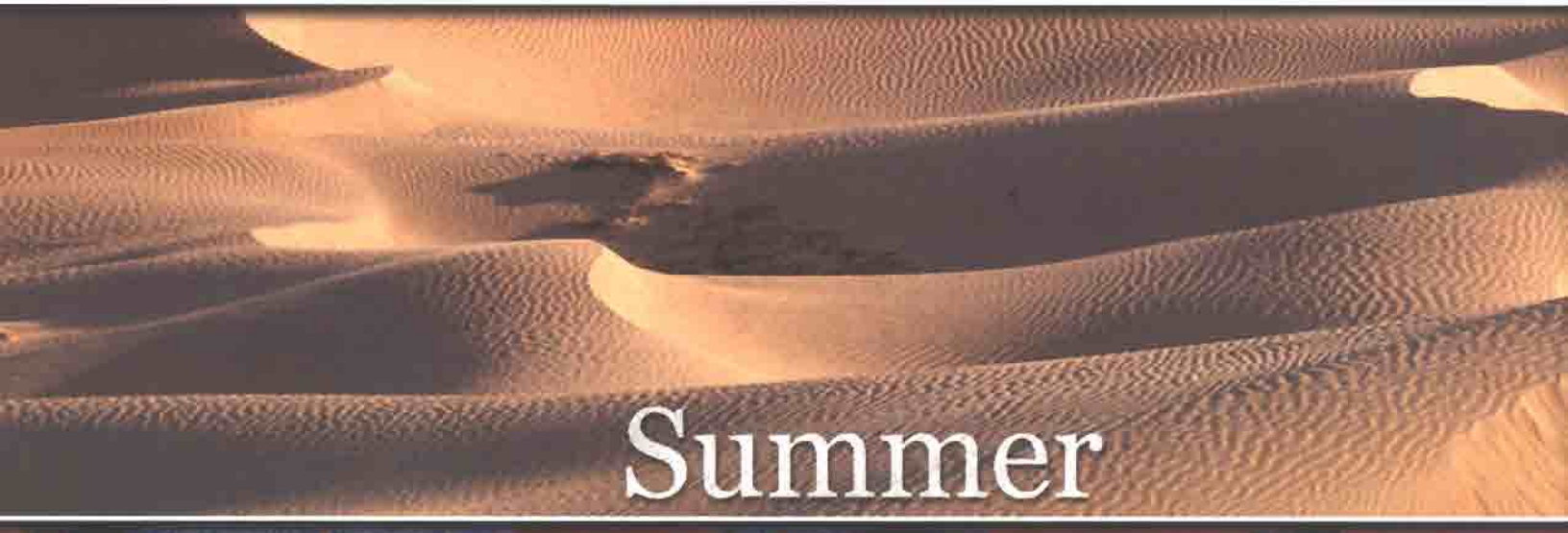
Season	Terminology	Dates/Period of Occurrence	Characteristics
Summer:		**1 June- 8 October**	
	Bareh Al-Jaouza' (First) or Bareh Al-Kabeer	9 June- 16 July	Hot weather, beginning duststorms, effect of monsoon low pressure.
	Summer Arba'eeneyah or Al-Bawarih	6 June- 15 July	Dry and hot winds from the northwest; some duststorms.
	Humid Weather		
	Al-Jaouza' (Second)	16-28 July	
	Summer Bahoura	23-30 July	
	Al-Merzam	29 July- 10 August	
	Al-Kulaibain	11-23 August	
	Suhail Appearance (Canapus Star)	Seen during 1-25 September	Break in temperature record, beginning of the "end of summer" season.
Fall:		**9 October- 27 November**	
	Al-Wasem	15 October- 3 December	Early rainfall in mid-October; it brings flourishing spring season in the desert.
	Al- Ohaimer	3-23 November	Severe thunderstoms and floods.
Winter:		**28 November- 12 February**	
	Arba'eeneyah or Al-Marba'aniah	5 December-15 January	Very cold days affected by the Shamal winds.
	Al-Butain	2 January- 7 February	Cold and rainy.
Spring:		**13 February- 8 May**	
	Bard Al-Ajouze	26 February- 8 March	Cold days after warm spring days.
	Al-Soubaq	11 March- 10 April	Severe thunderstorms, usually during the afternoon and during early morning hours, followed or accompanied by severe duststorms; occurring usually end of March and before the Al-Sarrayat begins.
	Bareh Al-Thouraya or Bareh Al-Sarrayat or Al-Sarrayat	15 April- 27 May	Severe local thunderstorms, occasionally accompanied by severe duststorms; which are dangerous to fishermen and people at sea.
Transitional Season:		**9-31 May**	Spring ends; hot weather increases remarkably.

Table 4b. Local Terminology of Seasons in Kuwait

Season	Period	Duration (days)	Remarks
Summer:			
Al-Kinah	29 April- 6 June	39	Beginning of hot weather.
Al-Thurayah	7-19 June	13	Al-Bawarih.
Al-Tuwaibaia'	20 June - 2 July	13	Hot weather (air).
Al-Jaouza' (First)	3-15 July	13	Simoom.
Al-Jaouza' (Second)	16-28 July	13	End of Bawarih.
Al-Merzam	29 July - 10 August	13	Jumrat Al-Qaith.
Al-Kulaibain	11-23 August	13	Humid weather.
Suhail Appearence	24 August - 14 October	52	Reduction in summer heat.
Fall:			
Al-Wasem	15 October - 5 December	52	Beginning of rainy season.
Winter:			
Al-Marba'aniah (Winter Arba'eeneyah)	6 December to 14 January	40	Cold weather.
• Al-Ikleel Stars	Appearance: 7 December		
• Qalb Al-Aqrab/ Al-Ahmar Star	Appearance: 20 December		
• Al-Shaulah Stars	Appearance: 2 January		
Al-Shubat (including one week of Al-Izaireq)	15 January to 9 February	26	Cold and humid weather.
Al-Izaireq	24-30 January (7 days)		
Spring:			
Al-Aqarib	10 February to 7 March	26	Last of cold weather and beginning of spring season.
Al-Ajouzah/Al-Thira'an	8 March to 2 April	26	End of spring season.
Al-Hameem	3-28 April	26	Relatively warm.
Total days		365	


Winter


Spring


Summer


Autumn

1. Winter Season (28 November- 12 February). Winter is the wettest and coldest season in Kuwait. The winter season in Kuwait is characterized by a substantial drop in temperature, accompanied sometimes with clouds and rain, with relatively cold northwesterly winds, locally called *Shamal*. The mean air temperature in January is 12.7 °C. The minimum temperature drops to 0 °C on some winter nights. Occasional unpredictable southeasterly winds may bring precipitation and occasional duststorms. The winter season is divided into two parts:

First part: The first part of the winter season runs from 28 November to 12 December, with a duration of about 15 days. Generally, during this period, the weather is fair during the day, but rather cold at night. The daily maximum of 13 °C may drop to 3.3 °C. Warm and humid interludes affect the country during the prevalence of the southeasterly (*Koas*) winds (daily maximum 23 °C, and may rise to 31.3 °C).

Arba'eeneyah or *Al-Marba'aniah* is a local name for 40 days of relatively very cold weather brought on by the effect of the *Shamal* winds. It starts from 5 December and continues to 15 January.

Second part: The second part of the winter season starts about 13 December and continues to 12 February, for a duration of about 62 days. Cold days and nights characterize the weather at this time of the year. Following the prevalence of southeasterly winds *(Koas)*, cloudy skies are common, as is the possibility of rain. After the southeasterly winds, cold and dry northwesterly *Shamal* winds prevail. Temperatures may drop to below freezing, with the possibility of frost occurring at night. Kuwait's coldest temperature of -4 °C was recorded at Kuwait International Airport on 20 January 1964. Fog may occur, particularly during calm nights.

Albutain is the local name for the cold rainy period from 2 January to 7 February.

2. Spring Season (13 February- 8 May). The spring season is characterized by mild weather, with changeable temperatures accompanied sometimes by rain and thunderstorms, with hot southerly winds. The spring season is divided into three periods.

First part: The first part of the spring season starts on 13 February and continues to 10 March (duration about 26 days). The weather during this time is cold at night and fair and pleasant during the day. Daily temperatures start rising markedly after mid-February, and precipitation decreases. The prevailing wind during this period is southeasterly, which brings warm-to-hot air and thunderstorms (locally known as *Sarrayat*). During the period from late February to early March, a sharp decline in air temperature can occur due to the extent of the polar continental air masses, and the temperatures may drop to as low as 0 °C, as was recorded in March 1985 during the *Bard Al-Ajouze* period.

Second part: The second part of the spring season runs from 11 March to 10 April (duration about 31 days), and is considered the finest weather of the year. A fluctuating temperature characterizes this period, especially when the southerly hot current of tropical air mass prevails. This period is known locally as *Sehally*, and lasts for several days. Maximum temperatures may reach 41 °C (13 to 14 °C above average); however, semi-cold northwesterly winds often occur, causing the temperature to drop noticeably. These winds may be accompanied by thunderstorms and heavy rains (*Al-Soubaq*, a local name for severe thunderstorm activity in the afternoon and early morning hours at the end of March; the *Al-Soubaq* precedes *Al-Sarrayat*), particularly during the period from 11 March to 10 April, which can be associated with violent duststorms, during which visibility may be limited to a few meters only. These storms are very dangerous due to their rapid development without prior warning, and are particularly dangerous to boaters and fishermen. The mean wind speed of these storms is 20 to 25 knots. It is noteworthy that the air behind the thunderstorm is remarkably cool (sometimes, 12 °C cooler than the ambient air).

Third part: This period extends from 11 April to 8 May (duration of 28 days). The weather during this period is characterized by being fair at night, and warm during the day, with unstable weather and local thunderstorms. Unexpected duststorms occur at times.

Bareh Al-Thurraya or *Bareh Al-Sarrayat* or *Al-Sarrayat* are local names for severe thunderstorms, which occur from 15 April to 27 May, and can cause considerable damage and endanger the lives of boaters at sea.

Al-Sarrayat. This term is used for local thunderstorms. Usually, thunderclouds develop in the afternoon or at night and are occasionally accompanied by severe duststorms, during which the visibility may fall to near zero. Heavy rains may occur during a very brief period (e.g., maximum rainfall of 38.4 mm in a period of just 20 min was recorded on 4 April 1976

at Kuwait International Airport). The southeasterly winds during this period become hot and humid in the afternoon, and temperatures start to exceed 28 °C. Convective clouds develop along a line parallel to the coast of the Gulf, about 15 to 25 km inland. The thunderstorms progress through three stages, sometime in less than an hour:

1. Cumulus stage: A cluster of cumulus clouds forms by convergence and the updraft of the warm southeasterly winds.
2. Mature stage: Rain starts reaching the ground and thunderclouds start to form (cumulonimbus clouds). This stage continues for 10 to 20 min over an area with strong winds, with gusts reaching 100 to 120 km/h, as recorded in some areas of Kuwait City.
3. Dissipating stage: The updraft of the southeasterly winds starts to weaken, and the cooler downdraft winds spread over the entire cell of the cumulonimbus clouds. The cumulus cloud system starts to separate into numerous parts, and the thunderstorm ends.

The transitional period starts when the spring season ends. This period usually occurs from 9 to 31 of May (duration of 23 days). It is characterized by a considerable increase in temperature and humidity, with severe duststorms at times. During this period, temperatures increase and can reach 44 °C. Winds are mostly variable; they may be northeast, northwest or southeast. The sky is nearly cloudless during this period.

3. Summer Season (1 June to 8 October). The summer season is characterized by very hot winds *(Al-Simoom)* and duststorms. The months of July and August are very hot, during which, the maximum temperature can exceed 51 °C. The diurnal range of temperatures in summer is extremely wide (about 22 to 31 °C), and the summer sky is almost cloudless. Summer winds blow from two main directions, namely, the northwest, and, to a lesser extent, the southwest. Duststorms occur mostly during June and July, and to a lesser degree from October to December. These dust storms bring large quantities of terrigenous material to Kuwait. The northern coastal area of Kuwait is more subject to the dust storms than is the southern coastal area.

The summer season is divided into three periods:

First part: This occurs from 1 to 23 June (duration of 23 days) and is characterized by hot weather. The beginning of the summer duststorm season starts with the effect of the low pressure monsoon (*Bareh Al-Jaouza'* or *Al- Bareh Al-Kabeer* from 9 June to 16 July). The summer *Arba'eeney* meaning "forty days", sometimes referred to as *Al-Bawarih,* is typified by dry and hot winds, which prevail from the northwest most of the time for 40 days. Duststorms characteristically occur from 9 to 12 and 17 to 24 June.

Monsoon, which is taken from the Arabic word *Mausim*, meaning season, refers to the wind that changes direction with the change of seasons. The monsoon in the Indian Ocean blows from the southwest, generally from April to October, and from the opposite direction, the northeast, from October to April. The southwest or summer monsoon is usually accompanied by heavy rain in areas of India and the East Indies, constituting the dominant climatic event of the area.

Second part: This period occurs from 24 June to 31 August (duration of 69 days). *Al-Simoom* or the "poison" winds start during this period and are characterized by dry, hot northwesterly winds; they may be continuous and not interrupted by winds from another direction. The winds range between strong to light and, sometimes, cause extensive duststorms (especially when the wind speed exceeds 16 km/h), during which visibility deteriorates to a few meters, particularly at noontime. The daily mean maximum temperature ranges between 42 and 46 °C. Very hot weather and extreme temperatures are recorded during this particular period. The highest temperature ever recorded at Kuwait International Airport was 51.3 °C on 11 August 1998. Duststorms continue in July and are likely to occur during 1 to 17 July. Very humid and uncomfortable weather sometimes occurs in August, especially when the *Koas*, southeasterly winds, prevail.

Humid Spells
Al-Jaouza' **(second) 16 to 28 July**
Summer *Bahoura* 23 to 30 July
***Al-Merzam* 29 July to 10 August**
***Al-Kulaibain* 11 to 23 August**

The humid spells usually begin about 20 July and may continue with interruptions until the end of October. During the humid intervals, light easterly and southeasterly winds predominate. Because these winds are approaching over a water source (Arabian Gulf), they are saturated with huge amounts of water vapor. High humidity during these intervals serves to make the heat more exhausting, particularly when winds are calm. During some of the intervals, winds blow from the northwest until noon time, but, due to the sea breeze, they veer northeasterly to easterly in the afternoon, southeasterly till the evening, southerly till midnight, and then westerly until sunrise. The humid spell may range from two to 20 continuous days, especially during the intervals 18 to 29 July and 6 to 29 August. Clouds may appear during these intervals and the occurrence of thunder and rain is not unexpected, although they are rare. A "trace" of rain was recorded in some areas of Kuwait on 26 July 2001. The daily mean maximum temperature is 45 to 46 °C.

Third part: The third period runs from 1 September to 8 October (duration of 38 days). Humid intervals continue to predominate during the period 15 to 29 September. The *Al-Simoom* winds no longer prevail, and temperatures start decreasing noticeably after 11 September. Maximum daily temperatures decrease from 42 °C at the beginning of this period to 36 °C at the end. Land and sea breezes are conspicuous, and clouds start forming. The weather is unpleasant and humid if the winds are southeasterly, but, if the winds are northwesterly, the weather is mild during the day and comfortable at night. The *Suhail* Star, which can be seen in the southern sky, is related to the transition in the temperature and indicates the end of the summer season.

Suhail, which is the Arabic name for Canapus Star, appears on 5 September. It is an important star for the people in the Arabian Peninsula, and can be observed in Kuwait from 1 to 25 September.

4. Fall Season (9 October to 27 November). During the fall season, variable winds switch from the southeast to the northwest. Clouds with some rain are common, especially when the southeasterly winds are blowing. The fall season is divided into two periods.

First part: This occurs from 9 October to 4 November (duration of 27 days), and is characterized by a substantial drop in temperature, with occasional humid weather when winds are calm. The effect of land and sea breezes continue. Clouds become common and the rainy season starts *(Al-Wasem)*.

Al-Wasem is a term well known in Arabia for early rainfall in the desert in mid-October (duration 15 October to 3 December). The *Al-Wasem* rainfall helps the seeds of desert vegetation to sprout prior to the onset of winter. This early rain results in a particularly abundant vegetative cover, with carpets of flowers, during the spring season.

Second part: The latter part of the fall season occurs from 5 to 27 November (duration of 23 days). It is characterized by fair weather most of the time, but, sometimes, temperatures fluctuate and clouds and rain occur during this period *(Al-Ohaimer)*. Severe thunderstorms may cause floods, as happened on 11 November 1997.

Al-Ohaimer occurs from 3 to 23 November, and is characterized by severe thunderstorms and possible floods.



Desert flowers in bloom (photo by Dr. James Bishop).

Climate of Kuwait

The climate of Kuwait is hot and dry and sometimes dusty in the summer; cold with some rain in winter. It is characterized by short spring and fall seasons.

Kuwait's climate is, in general, a desert type climate.

There are five major factors that affect and determine the climate of Kuwait for different seasons:

1. The semi-permanent pressure systems in each season, such as the cold Siberian high pressure and its ridge over the Arabian Peninsula in winter, the thermal lows of Sudan's low pressure extending over the Arabian Peninsula in the spring and fall, and the great southwest Asia monsoon low in summer.
2. The passing depressions and their associated weather activities in winter and transitional seasons.
3. The water vapor sources, consisting of the Arabian Gulf, the Gulf of Oman, the Arabian Sea, the Indian Ocean and the Red Sea.
4. Sunshine in Kuwait has a more direct effect and for a greater number of hours in summer. The altitude angle of the noon sun reaches 84° on 21 June (Fig. 27a) and the sunshine duration is for 14 hours two minutes. During winter, the sun's rays strike the ground obliquely (Fig. 27b) and for a shorter period of time. On 22nd December, the sun's rays are at an altitude angle of 37° and strike the ground for 10 hours 15 minutes.
5. The topography and the location of a country (e.g., Kuwait) or a region have some role, and affect the climate of Kuwait and the Arabian Peninsula.

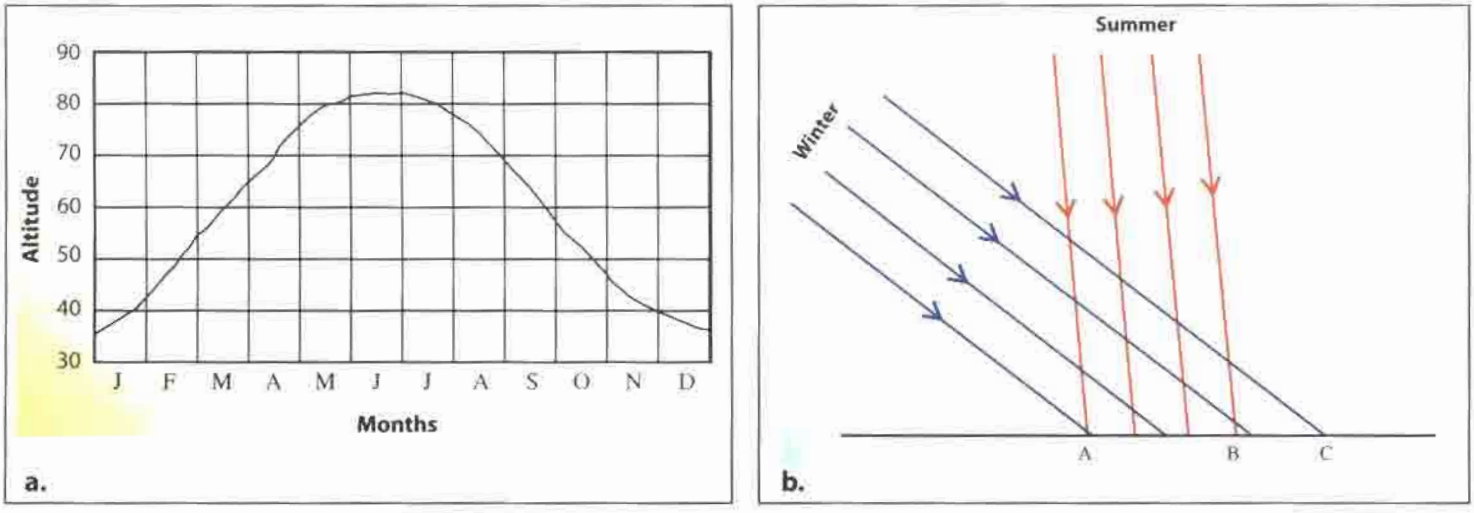


Fig. 27. Sunshine in Kuwait. a. Altitude angle of the noon sun for Kuwait (30 °N) during the different months of the year. b. Red lines indicate sun rays striking the ground during summer; blue lines indicate sun rays striking the ground during winter. An oblique ray of sun in Kuwait during winter is spread over a larger surface area (A-C, blue lines), than is a direct sun ray during summer (A-B, red lines).

The following table displays the daylight period (in hours and minutes) for each month in the State of Kuwait.

Month	Hours	Month	Hours
January	10:29	July	13:50
February	11:09	August	13:10
March	12:00	September	12:20
April	12:52	October	11:28
May	13:37	November	10:42
June	13:59	December	10:17

Air Masses. The Arabian Peninsula and the Gulf region have a moderate air mass contrast. The extensive Taurus and Pontic Mountains of Turkey and the western Caucasus Mountains of Iran seldom allow free flows of polar air southward. Therefore, polar continental air reaches north Arabia only in greatly modified form. The wide southern and eastern parts of Arabia allow ingress of tropical maritime air from the southern Arabian Sea (Fig. 28). Thus, Kuwait's climate is determined by the interaction of these two air masses.

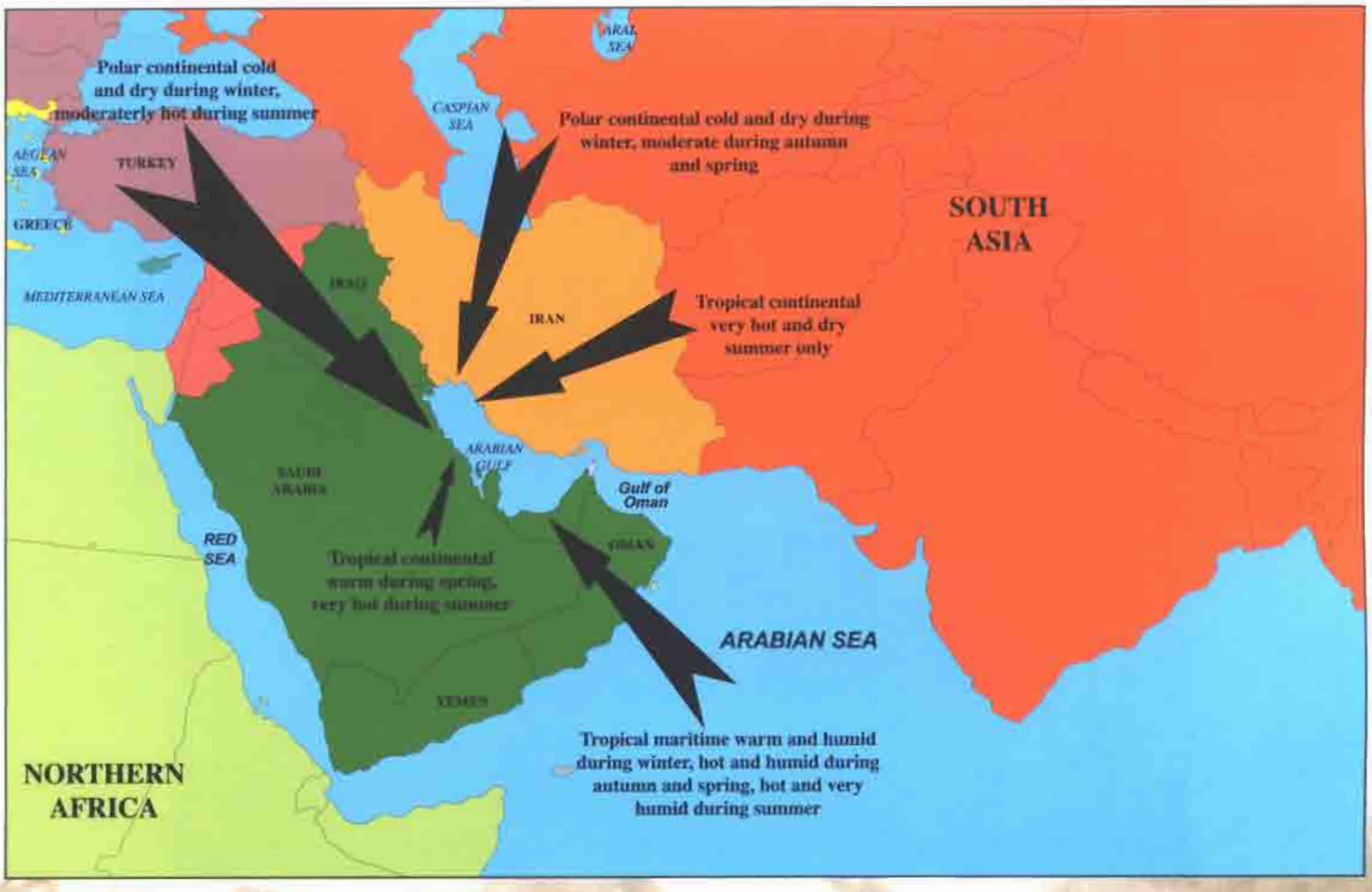


Fig. 28. Source of air masses that frequently affect Kuwait and the Arabian Peninsula.

Polar Continental Air Masses

The source region of these air masses in the winter season is the snow covered northern interior of Asia. From its source, air is very cold and dry. Temperature ranges from –15° by day to –25° C or lower at night.

An extension of the Asian anticyclonic system usually intensifies during winter over Anatolia and Iran and extends southwards over the Arabian Peninsula. As the air moves southwards from its source, it starts to warm and becomes more homogenized and modified. These modified polar air masses reach Kuwait and northeastern Arabia after the passage of the Mediterranean depressions and are manifested as cold and dry winds or NW *Shamal* winds (Fig. 29). Clear skies and surface inversions mostly occur. In January (during these air masses), temperature values range from 5° to 8° C at night and 12° to 16° C by day in Kuwait, whereas in some extreme cases, the temperature may fall to below freezing (e.g., – 4° C), as was recorded in January 1964. Duststorms occasionally result from the cold, strong winds caused by the polar air masses.

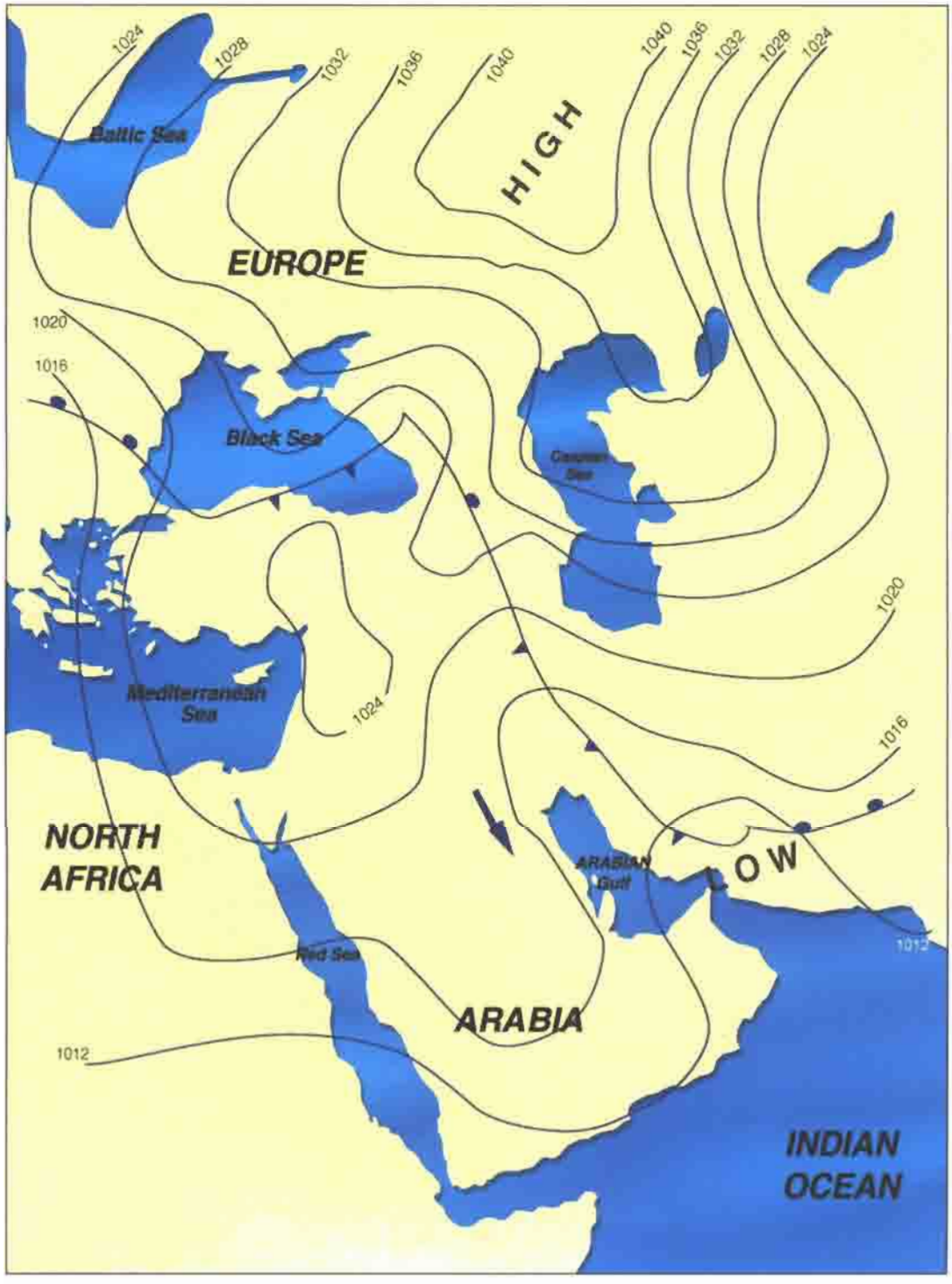


Fig. 29. Synoptic map showing the polar air mass extending to the Arabian Peninsula.

Polar Maritime Air Masses

The source region of these air masses is the cool water of the northern Atlantic Ocean. They reach the Arabian Peninsula occasionally during the cool season behind the western depressions. In the summer, the air mass intensifies simultaneously when the monsoon low pressure extends northwest to Arabia, occassionally reaching the eastern Mediterranean Sea and producing a steep pressure gradient (Fig. 30). This situation causes strong *Shamal* or NW winds to affect the loose dust in desert areas resulting in duststorms, which last 10 hours a day or longer. This cooler air mass drops the temperature in the summer, especially in July, from 45° to 42° C.

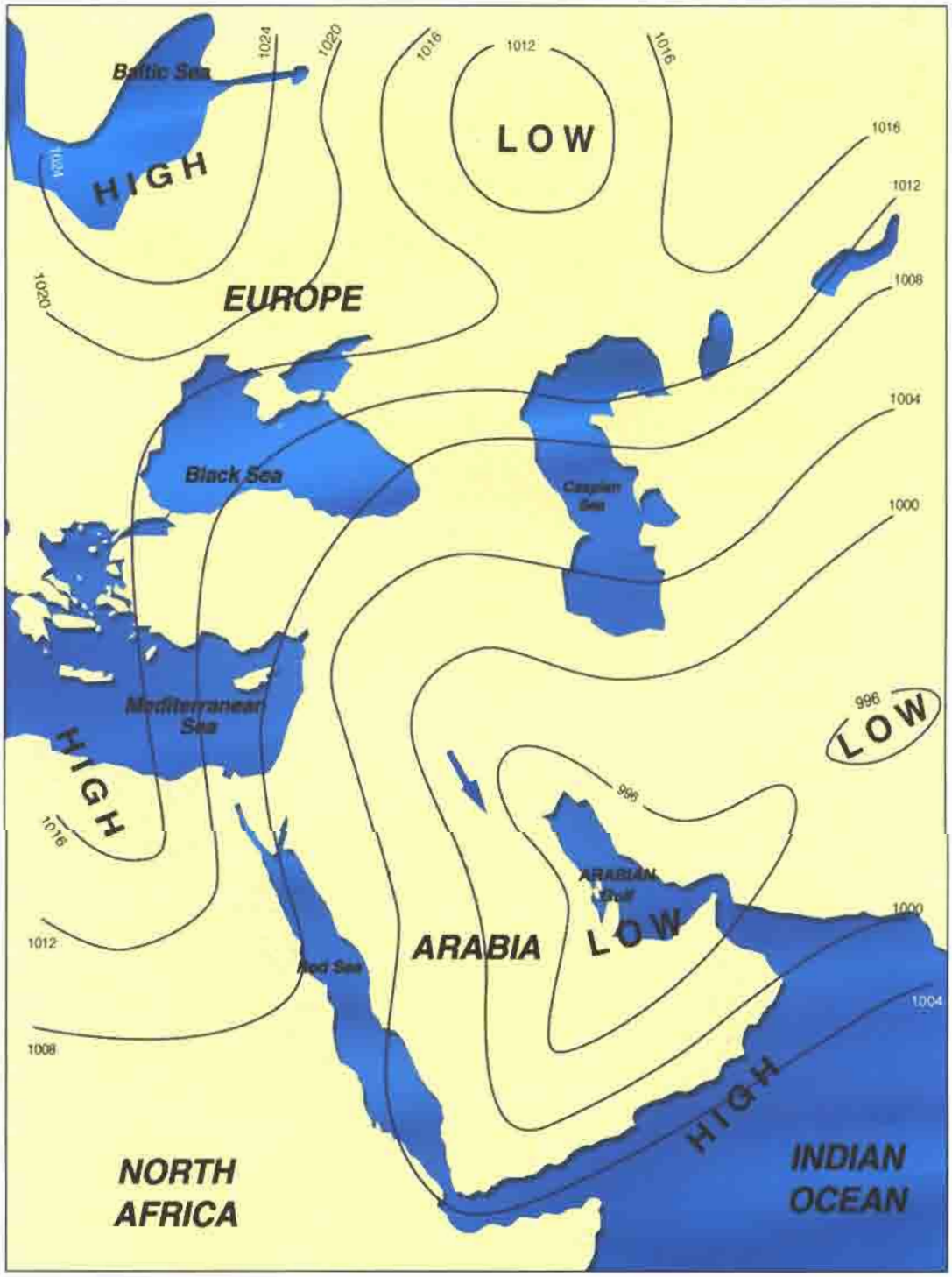


Fig. 30. Synoptic map showing an extension of the Atlantic air mass over the Mediterranean and north Arabia and to the southeast the extension of the monsoon low pressure (Tropical continental airmass).

Tropical Continental Air Masses (Arabia)

These air masses are produced from the central Arabian Peninsula, as the air becomes excessively hot and dry due to strong solar surface heating (Fig. 31). The westerly or southwesterly winds from these air masses bring the temperatures to record highs during spring and summer seasons.

Tropical Continental Air Masses (NW India)

These air masses strongly influence the weather of Oman (Fig. 31), which experiences a misty and rainy season in summer (summer monsoon), whereas summer in Kuwait and Saudi Arabia is very dry and hot. Kuwait, being west of this system, has NW winds (*Shamal* winds).

This active monsoon air mass of semi-persistent northwesterly wind tends to dominate Kuwait's weather in June, July and during occasional intervals in August and September, increasing duststorms and hazy skies. The temperature ranges from 46° C or more by day to nearly 29° C by night. It is noteworthy to mention that the *Shamal* or NW wind current becomes heated as it descends the Iranian Zagros Mountains.

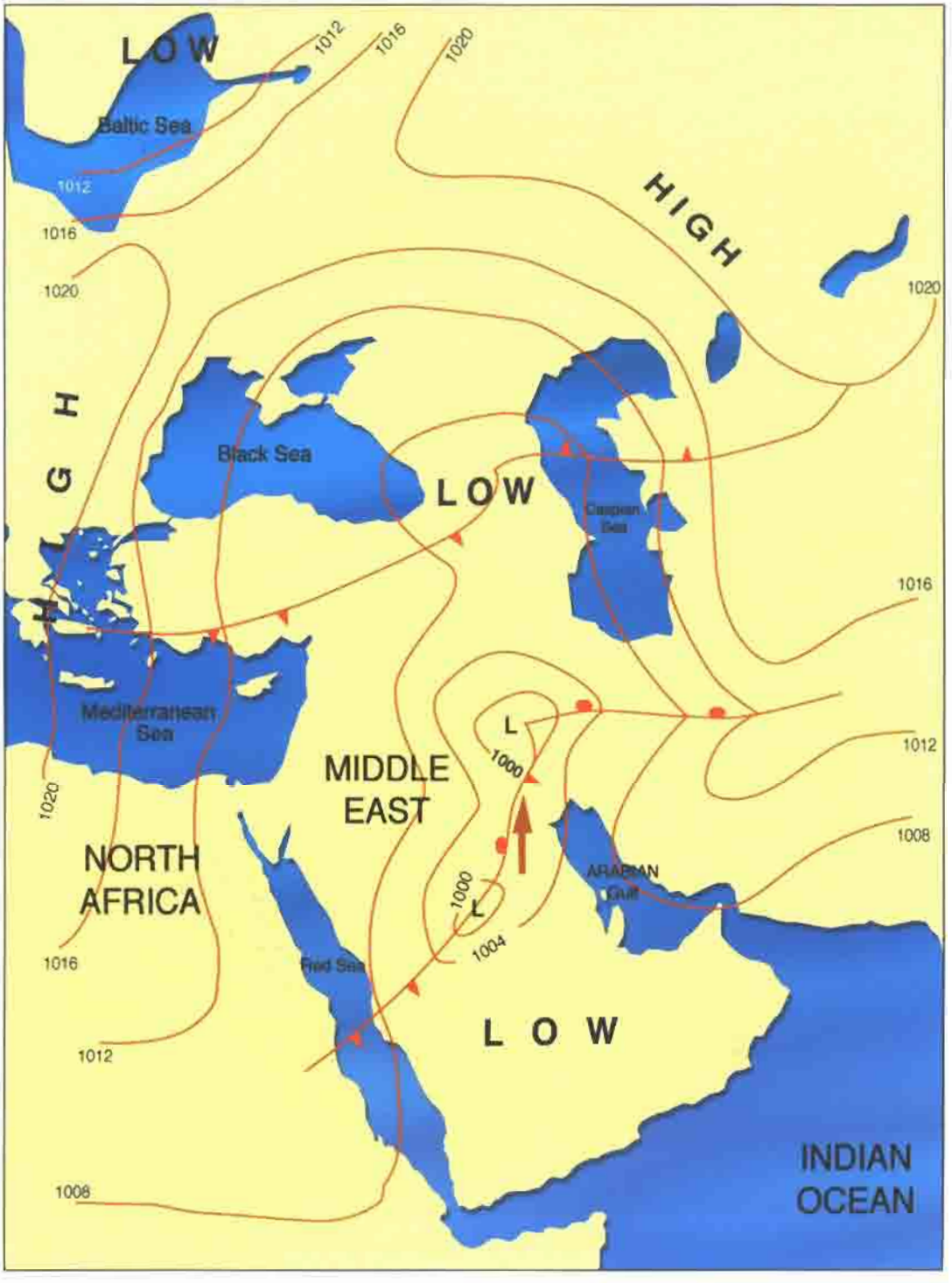


Fig. 31. Map showing the tropical continental air masses affecting Arabia.

Tropical Maritime Air Masses (Arabian Sea)

Tropical maritime air masses originate in the Arabian Sea and northern part of the Indian Ocean. They are characterized by being warm with high moisture content because of their source. These air masses are drawn northwards in winter by the attraction of the Mediterranean depressions (Fig. 32). Mist and fog are not uncommon, particularly in the southern parts of the Arabian Gulf. Convective rain and showers may occur along the eastward passage of the low pressure system, with their centers situated northward of Kuwait. During winter, these air masses are responsible for warm fronts associated with large amounts of low stratus clouds, and the occurrence of continuous rain.

In the second half of the summer, especially August and September, following the weakening of the monsoon low pressure, this air mass starts to move northwards over the land resulting in oppressive humid hot spells. Kuwait's geographic location and climatic regime can result in rather extreme conditions for the marine environment. The combination of some physical factors, such as the high summer temperature, the high rate of evaporation, the low rainfall, shallowness of the water column, and the lack of active circulation in certain locations, all contribute to produce stressful conditions for Gulf biota. A good example of stressful conditions was observed during the summer of 2001. Seawater

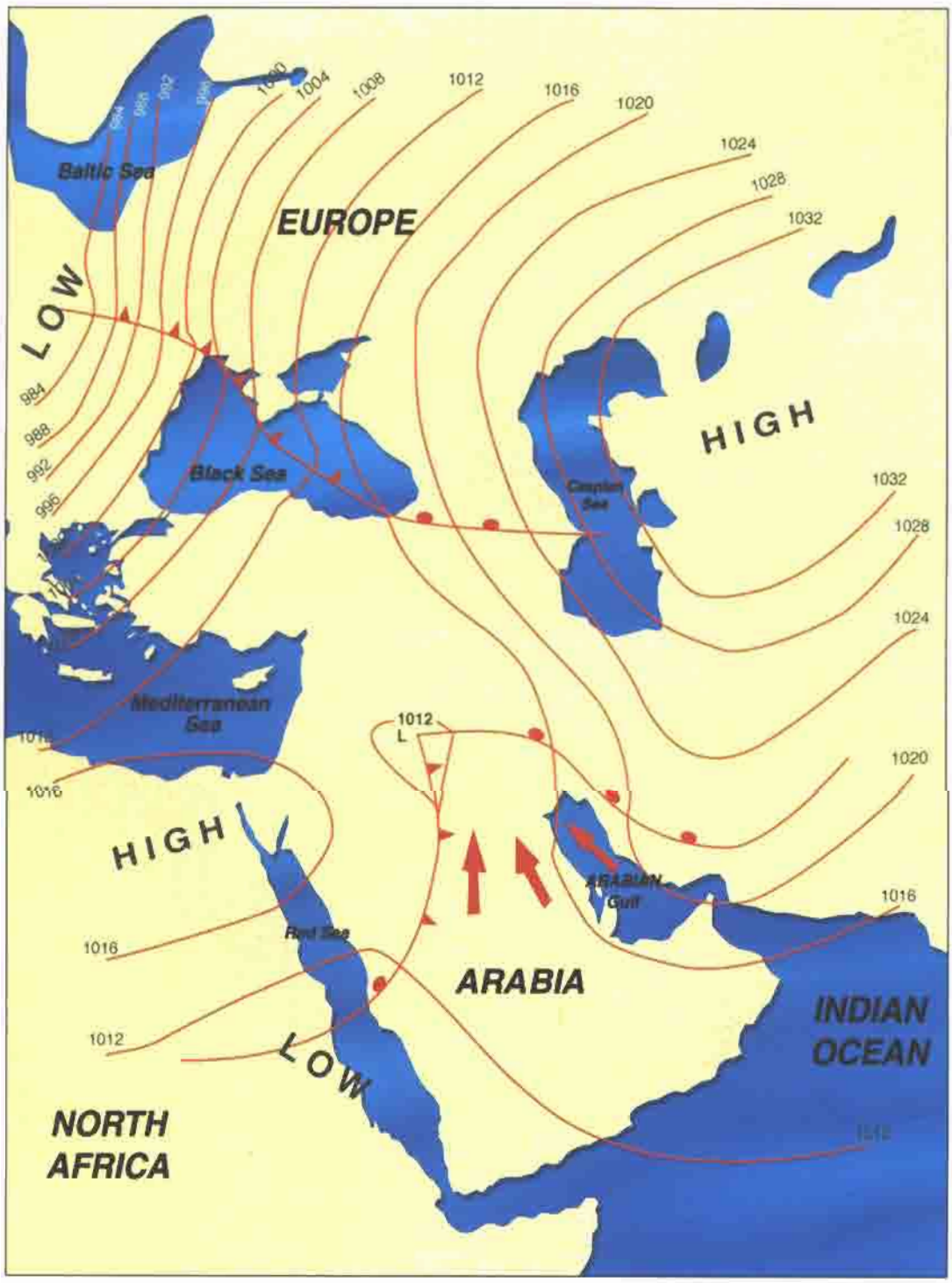


Fig. 32. Map showing tropical maritime air mass being drawn northwards by the Mediterranean depression.

temperature in Kuwait Bay reached 36° C for the period of 1-14 August 2001, relative humidity was high (99%) from 5-11 August 2001, and wind speed was about zero m/s from midnight to 9 a.m. during 1-15 August 2001, contributing to water stagnation in the embayment with concurrent fish kill.

Monsoon

The monsoon is one of the most dramatic climatic phenomena involving large areas, and playing a significant role in modulating the global climate. Monsoon is a term originally used by Arab mariners in reference to the seasonally shifting winds in the Indian Ocean and surrounding regions, including the Arabian Sea. These winds blow from the southwest (Fig. 33) during one half of the year and from the northeast (Fig. 34) during the other half of the year. Therefore, seasonal changes occur as northeast winds prevail in the winter (cold, dry air flows from the Arctic across Asia) in the Indian subcontinent and strong southwest winds prevail in the summer (wet summer with heavy rainfall from June to September). Other monsoons occur in Australia and Africa. The monsoon definition now denotes climatic systems anywhere in which the moisture increases dramatically in the warm season.

Sailors of the region used to wait for months in ports for the direction of the monsoon winds to change. The southwest monsoon (June-September) carried the ships to India, whereas the northeast monsoon (October - March) brought them back to Arabian shores and also took ships down the east coast of Africa.

The most biologically productive period in the Arabian Sea is during the summer monsoon, when prevailing winds cause nutrient-rich deeper waters to flow toward the surface. This "upwelled" water, loaded with nutrients and carbon dioxide, spurs rapid and widespread marine plant growth and subsequent marine animal production. In contrast, during the winter monsoon, carbon dioxide and nutrient flow from the depths to the surface falls off, and plant and animal productivity is low.

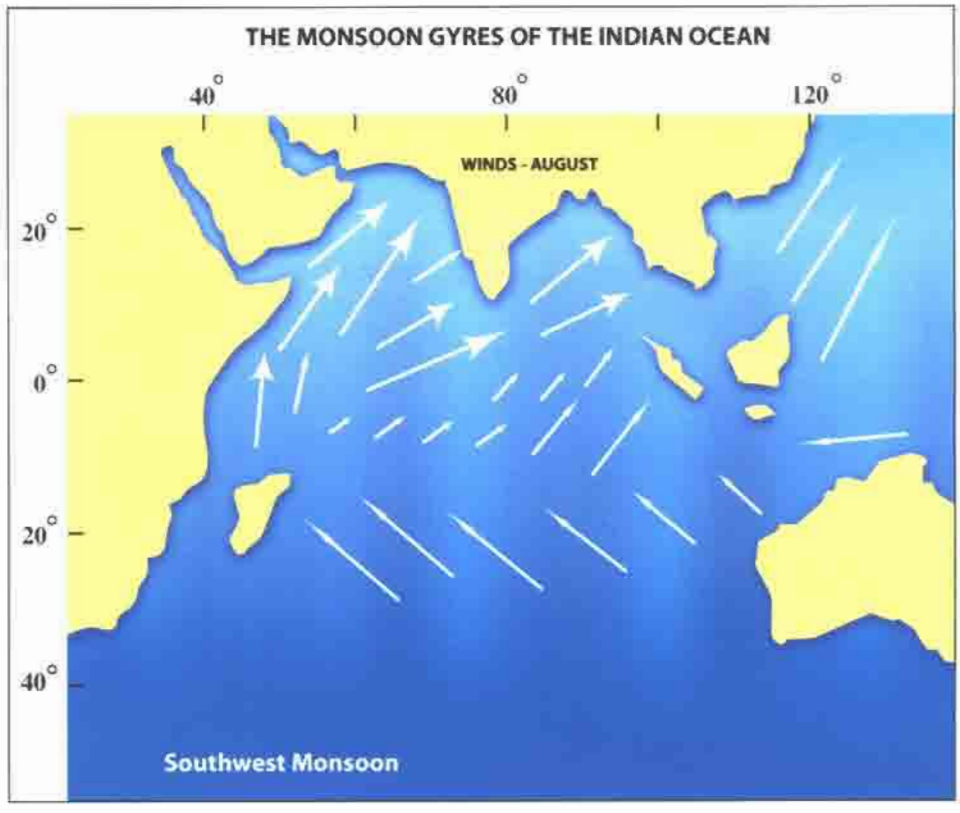


Fig. 33. Wind direction during the southwest monsoon.

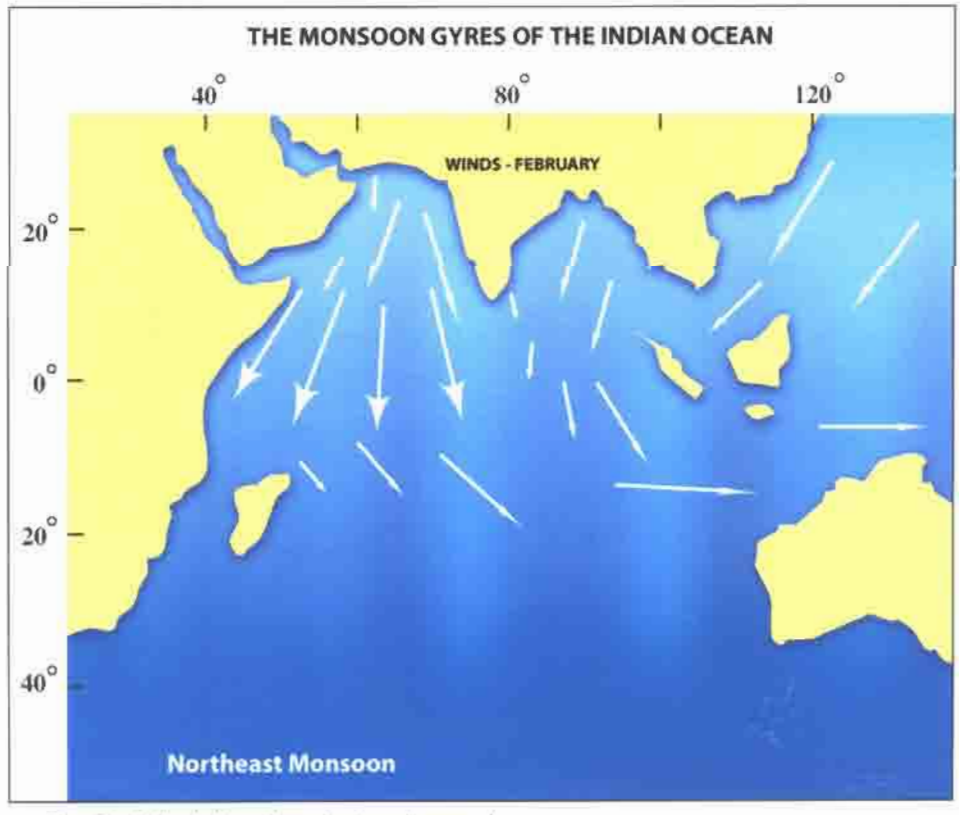
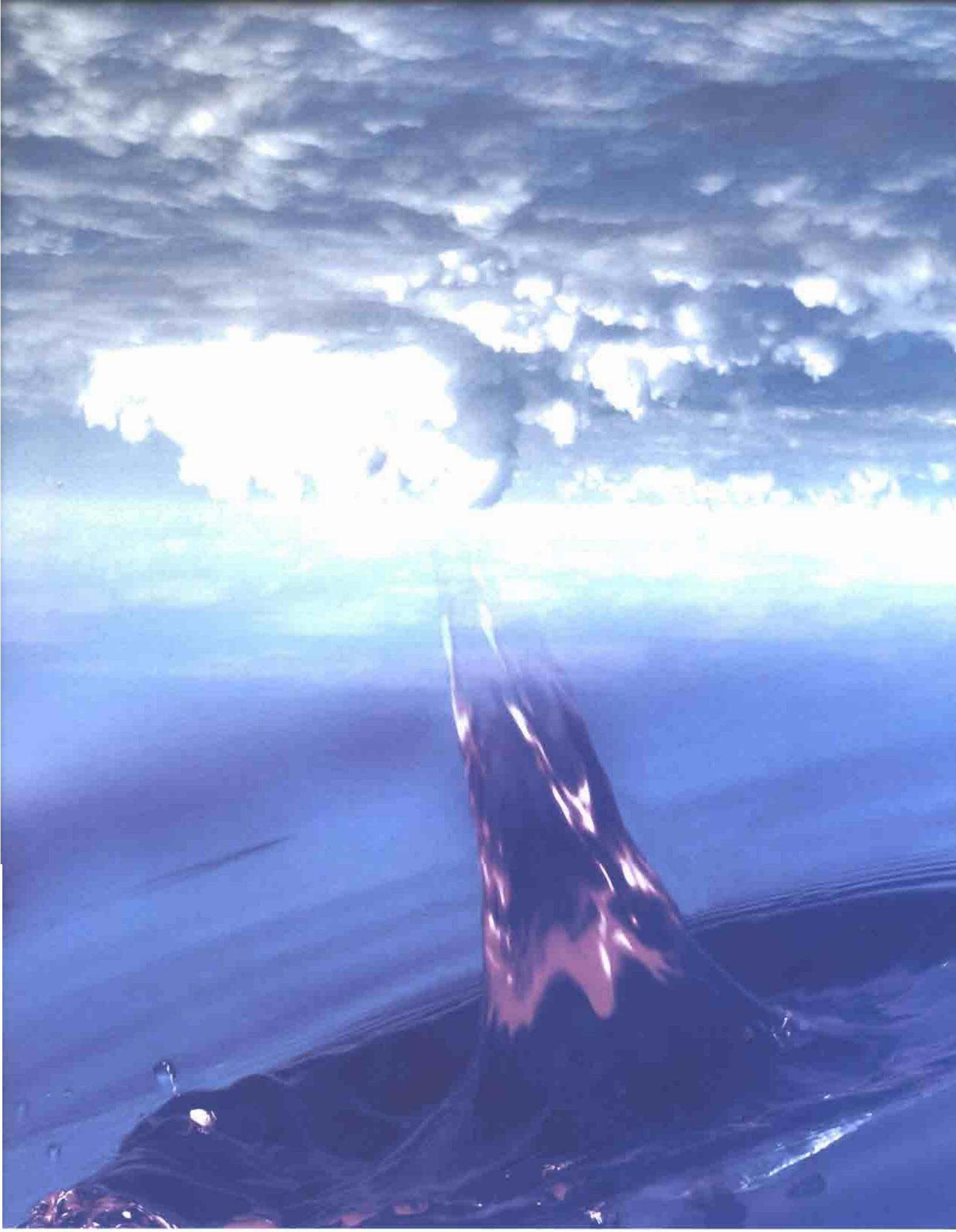
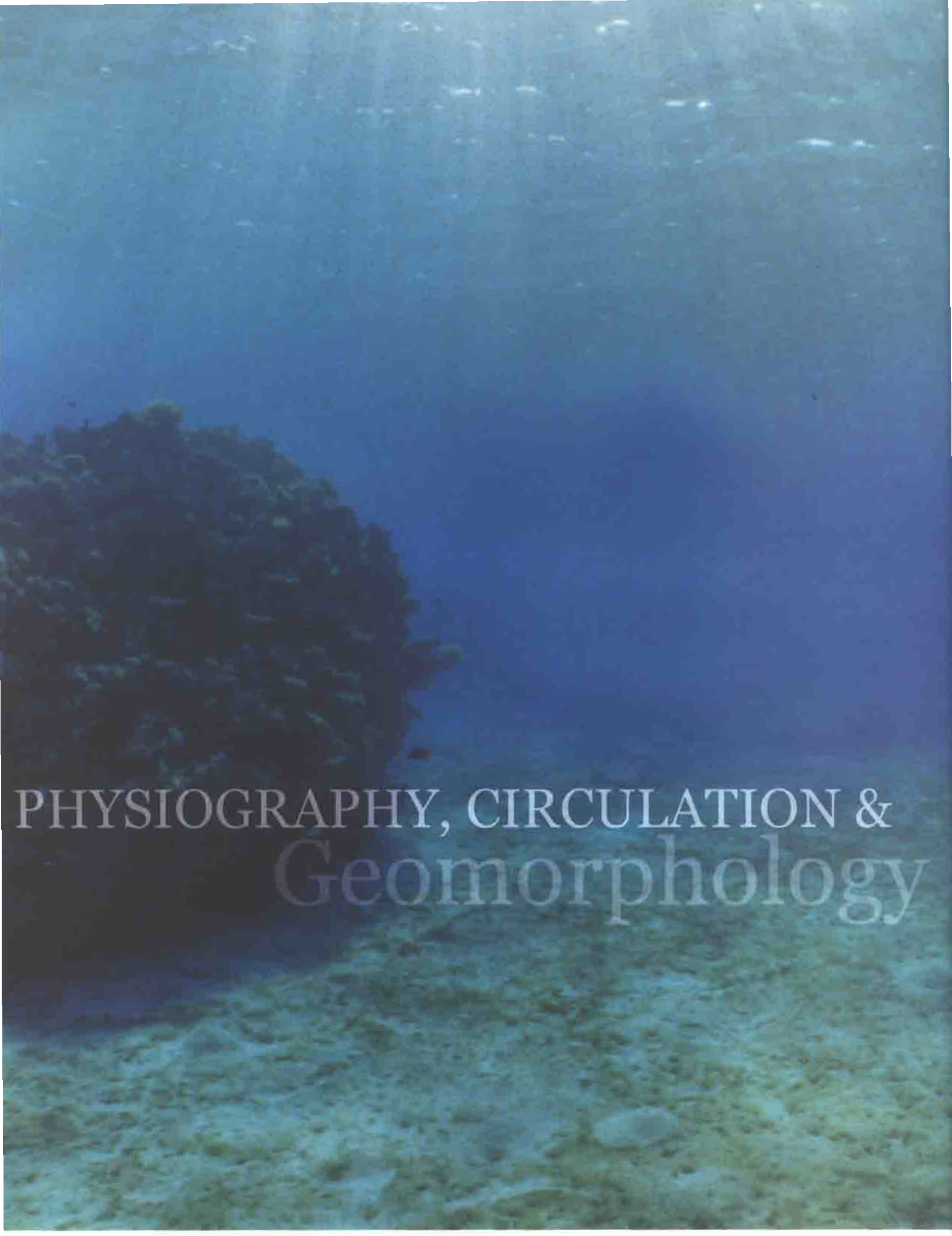


Fig. 34. Wind direction during the northeast monsoon.





PHYSIOGRAPHY, CIRCULATION & Geomorphology



PHYSIOGRAPHY, CIRCULATION AND GEOMORPHOLOGY OF KUWAIT'S WATERS

Bottom Topography and Physiography

Kuwait's marine area occupies the western edge of the Mesopotamian shallow shelf of the northern part of the Arabian Gulf. Five physiographic regions have been identified in Kuwait's bottom topography (Khalaf et al., 1984). These are 1) the submerged estuarine flat, 2) the submerged estuarine distributary channel and bar system, 3) the Kuwait Bay trough, 4) the shelf slope, and 5) the islands (Fig. 35). The submerged estuarine flat lies off the northern coast and includes most of Kuwait Bay and the area east of Bubiyan and Failaka Islands for about 35 km. This submerged estuarine flat covers a very shallow area not exceeding 10 m in depth of the Shatt Al-Arab estuary (Figs. 35 and 36).

The estuarine distributary channel and bar system consists of elongated estuarine lobes of clastic (i.e., fragments of preexisting rocks) sediments up to 30 m thick, extending almost 100 km seawards from the Shatt Al-Arab estuary toward the Gulf's longitudinal axis. Khor Al-Sabbiya is also considered as a submerged estuarine channel.

The Kuwait Bay trough is defined by the 20-m contour and extends from just north of the Dawhah Peninsula in Kuwait Bay eastward toward the open offshore area and then southward parallel to the coastline (Fig. 36). It is separated from the estuarine flat by the estuarine slope and from the mainland coast by the shelf slope. It is relatively narrow at its head in Kuwait Bay, and broadens toward the southeast.

The shelf slope extends along the coastal area to 20 m depth (Fig. 36). The shelf slope from Ras Al-Ardh to Al-Shuaibah is relatively steep and about 2 km in width (Fig. 35). South of Al-Shuaibah the slope is more gentle and extends out to a distance of 12 km near the Mina Saud area.

Nine islands are present in Kuwait's territorial waters (Fig. 36). According to their physiography, these islands are classified into two main groups. One group is coastal (six islands) and located in the northern waters. The coastal islands are Warba, Bubiyan, Miskan, Failaka, Awhah, and Umm Al-Namil. Akkaz Island belonged to this group, but was connected to Shuwaikh Port in Kuwait Bay during its construction and the tidal channel separating it from mainland was closed. Khor Al-Sabbiya separates Bubiyan and Warba from the mainland, and these two islands could be considered as part of the northern "submerged" estuarine flat. Umm Al-Namil Island (and formerly Akkaz Island which is now merged with Shuwaikh Port) is

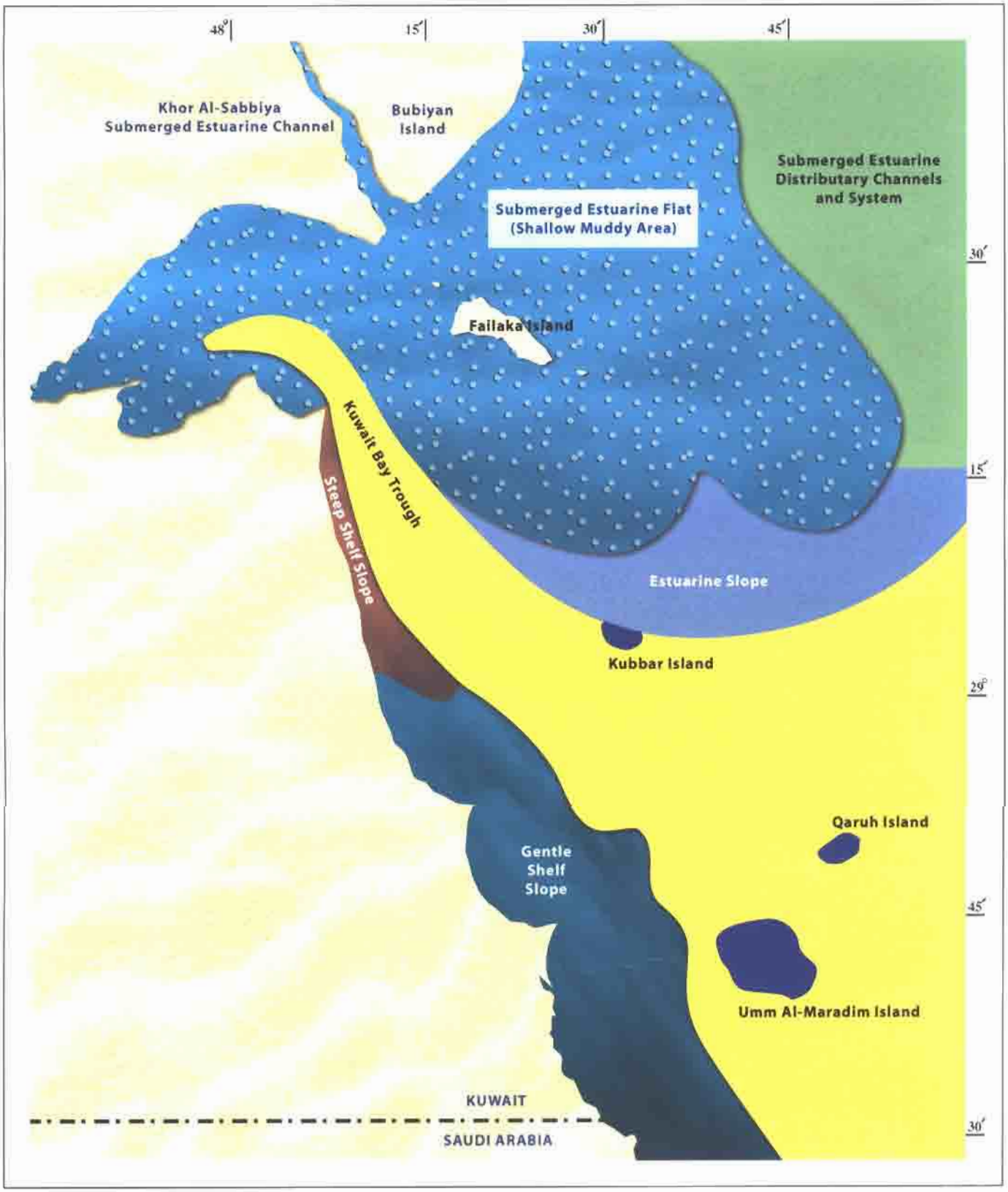


Fig. 35. Physiographic features of the seabed.

surrounded by extensive reefal flat (Fig. 37). The second group of islands (three islands) is located in the deeper waters off Kuwait's southern coast, and includes Kubbar, Qaruh, and Umm Al-Maradim (Fig. 36). These islands are physiographically different from those located in the northern area in that they rise abruptly from the sea floor. Descriptions of some of the islands are provided elsewhere.

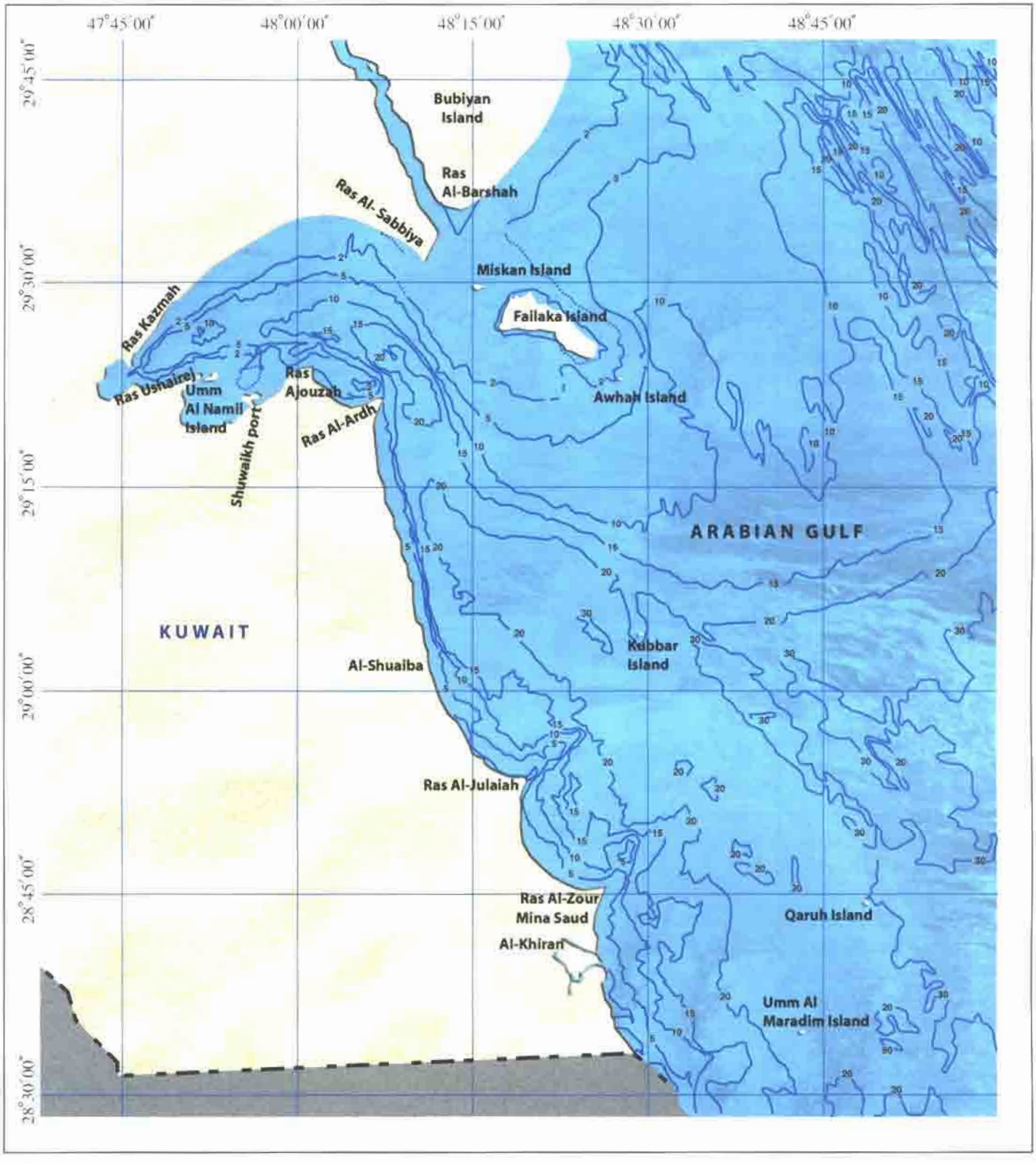


Fig. 36. Bathymetry map of the Kuwait's marine environment

Sedimentological Characteristics and Textural Classes

A variety of classifications and terms have been used to describe Kuwait's sediments. These classifications are based on either sediment content or particle size or a combination. The origins of these sediments are the Shatt Al-Arab estuary, aeolian dust fallout and direct chemical and biogenic precipitation (Khalaf and Ala, 1980; Al-Bakri et al., 1984). The surface sediments of the Kuwait offshore area are found to consist of seven textural classes (Fig. 37): sand (grain sizes from 0.063 to 2.0 mm), silty sand, muddy sand, sandy silt, sandy mud, silt, and mud (grain sizes finer than 0.063 mm = 63 µm).

The geographic distribution of the textural classes reveal that most of Kuwait's marine area is covered with just three fine-grained sediments, i.e., mud, sandy mud, and sandy silt (Fig. 37). These deposits are found in the deeper areas as well as the sheltered shallow offshore sites. Course-grained sediments (sand, muddy sand, and silty sand) are of limited distribution and are usually associated with the shallow rocky bottoms that are subjected to relatively strong waves and currents. Specifically, these course-grained sediments occur in the intertidal and nearshore areas from Ras Ajouzah (Kuwait Towers) in the north to Al- Khiran in the south. Course-grained sediments also occur around Failaka Island and the small islands in Kuwait's southern waters, and in the north-eastern territorial waters near Iraq (Fig. 37).

The sand-sized component of the sediment is composed, on average, of about 95 % sand, 3.6 % silt and 1.4 % clay. The average textural composition of the muddy sediments is 54 % silt, 43 % clay and 3 % sand. Muddy sediments cover a large portion of Kuwait's marine area. Sandy muds are the second most dominant textural class among Kuwait's sediments, and have an average composition of 42 % silt, 36 % clay and 22 % sand. Between the nearshore sand deposits and the offshore mud and sandy mud deposits, transitional textural classes occur in the following sequence: silty sand, muddy sand, and sandy silt. Silt deposits are very restricted and occur only in the extensive tidal flats of Kuwait Bay (Fig. 37).

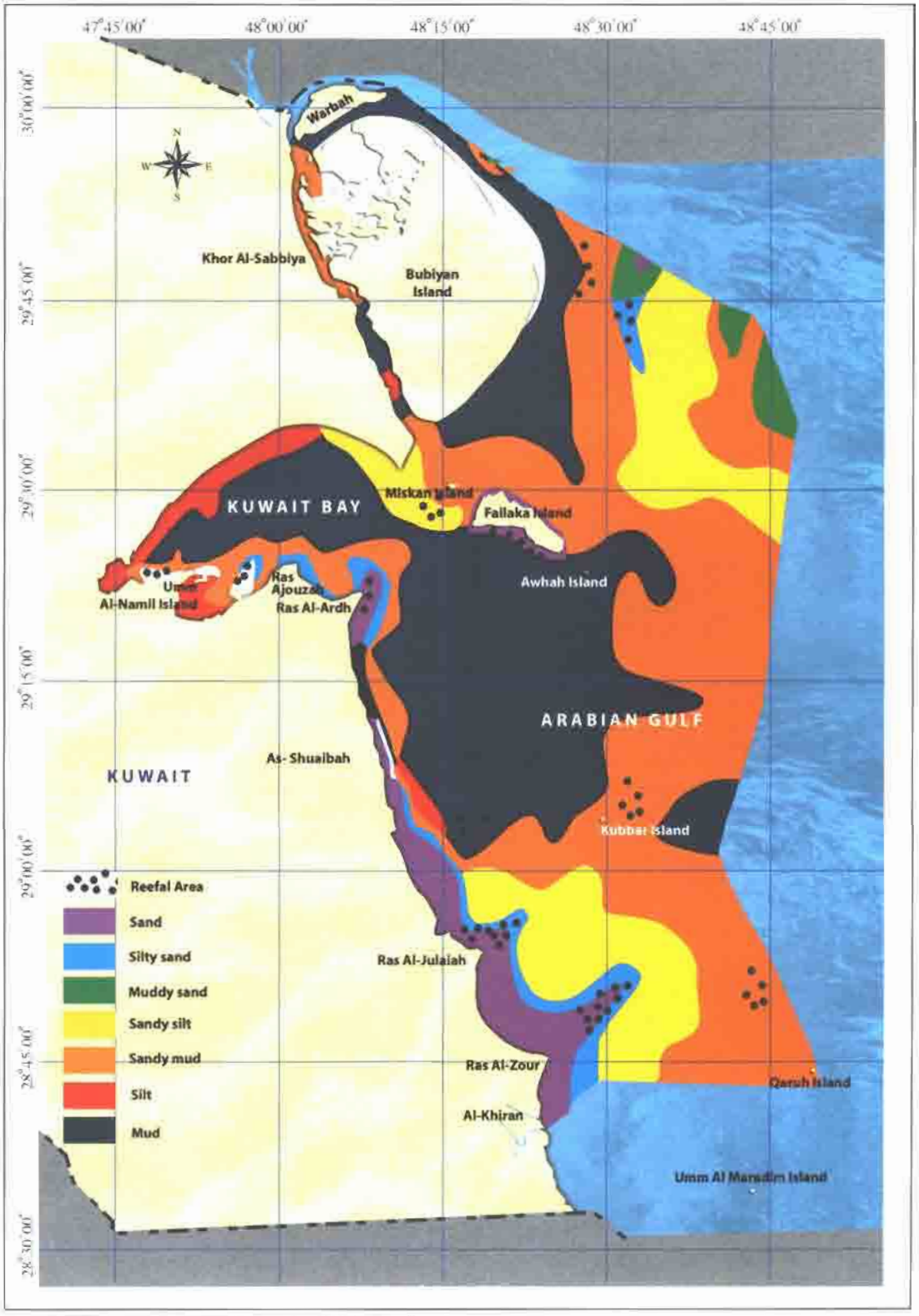


Fig. 37. Physiographic features of the seabed.

Coarse Fraction Components and Biolithofacies Classification.

The grain types of the sand fraction in the marine area are grouped under biogenic components (i.e., those derived from living organisms, usually mollusks), quartz, rock fragments, and feldspars. The biogenic grains are represented mainly by the shells and shell fragments of gastropods, bivalves, foraminifera and echinoids with lesser quantities of ostracodes, byrozoans, and sponge spicules. More than 90 % of the biogenic material originates from just three faunal groups, however. These are mollusks, foraminifera, and echinoids (Table 5). Biogenic grains increase in proportion with an increase in grain size, with the coarse and very coarse sand fractions being almost totally composed of biogenic grains. The average frequency percentages of these biogenic grains vary from 25 to 97 %. Using a classification system based on grain size, carbonate content, and common faunal origins results in nine biolithofacies categories for Kuwait's sediment (Fig. 38).

Quartz grains in the sand fraction of the bottom sediments of Kuwait's marine area ranged from 10 to 45 %. Quartz grains increase in percentage with the decrease in grain size. They are concentrated in the fine and very fine sand fractions and almost absent in the course and very course fractions. Unlike the biogenic components, the quartz content tends to be concentrated in the northern half of the marine environment.

Rock fragments are usually concentrated in the very coarse and coarse sand fractions. They are mostly represented by fragments of cemented calcareous sandstone that could be derived from beach rocks and ancient raised beaches. They are abundant in sediments located close to beach and coastal reefal flats.

Kuwait's sediments have been partitioned into a two-fold classification scheme using grain size and weight percent of carbonate. The term marl describes the fine-grained material (mud) and the term calcarenite denotes coarse-grained sediments (sand). Combinations of these two terms grade sediments from fine to course into four categories, i.e., marl, calcarenitic marl, marly calcarentie, and calcarenite.

Textural characteristics of sediments reflect Kuwait's offshore energy zones. Mud predominates where the wave and current energy is low, and sand and sandy deposits predominate where the energy is moderate to high. Tidal currents in Kuwait's offshore waters are rather weak, and most waves and surface currents are generated by the prevailing winds. Dominant wind directions are either northwest (NW) giving rise to the "*Shamal*," or southeast, which gives rise to the "*Koas*". The nearshore areas along the southern coast of Kuwait Bay are subjected to a maximum degree of agitation from

Table 5. Characteristic Features of the Various Biolithofacies Units of Kuwait Marine Sediments

Biolithofacies Sediment Type	Weight % mud (< 0.063 mm)	Weight % Carbonate Content	Mollusca %	Foraminifera and Echinoid %	Foraminifera: Echinoid Ratio
Molluscan marl	> 90	25 - 90	> 75	< 25	-
Foraminiferal marl	> 90	25 - 90	< 75	> 25	> 2 :1
Echinoid marl	> 90	25 - 90	< 75	> 25	< 2 :1
Foraminiferal echinoid marl	90	25 - 90	< 75	< 25	< 2:1 and > 1:2
Molluscan calcarenitic marl	50 - 90	30 - 90	> 75	< 25	-
Foraminiferal calcarenitic marl	50 - 90	30 - 90	< 75	> 25	> 2 :1
Foraminiferal echinoid calcarenitic marl	50 - 90	30 - 90	< 75	> 25	< 2:1 and > 1:2
Molluscan marly calcarenite	10 - 50	40 - 90	< 75	< 25	-
Molluscan calcarenite	< 10	> 50	< 75	< 25	-

the *Shamal*, as are the nearshore areas along the coast south of Kuwait Bay from the "*Koas*". In addition to waves, the wind causes long-shore currents, which, with the tidal currents, affect the shallow exposed areas more heavily than the deeper offshore and sheltered coastal areas. The higher energy areas prevent fine-grained sediment from settling, and thus only heavier course grained sediments remain. In sheltered coastal areas and in deeper offshore waters, the fine-grained sediment is able to settle and accumulate.

The general topography and climate of the surrounding region are affecting the overall textural characteristics of the bottom sediments. Because of the aridity and very low relief of the area surrounding the Arabian Gulf, there is no significant supply of fluvial coarse clastic material to Kuwait's offshore area. Aeolian sediments transported to the area by dust storms resulting from the prevailing NW winds are a major source to the total sediment budget (Al-Abdul Razzak et al., 1982; Sugden, 1963).

In summary, Kuwait's bottom sediment composition results from the interaction between autochthonous (produced in situ) calcarious fragments, mostly of biogenic origin, and allochthonous (from elsewhere) terrigenous detritus supplied to the area mainly by dust storms. Sedimentation is also influenced to a great extent by the hydrodynamic status and kinetic energy level of the water body, nature of the bottom, and climate. Kuwait's offshore area is a depositional environment with relatively little net sediment movement. Due to the fact that the average speed of both ebb and flood tidal currents is more or less equal, the net transportation distance of the sediment is negligible.

Some sediment movement does occur in areas of relatively high energy, which includes the southern offshore area of Kuwait Bay and nearshore area along the southern coast of Kuwait. In these areas, sediment moves parallel as well as perpendicular to the shoreline. There is a net sediment transport parallel to the coast. This transport may be affected significantly in the future because of the damming of the Tigris and Euphrates Rivers in Turkey, which will deprive the Shatt Al-Arab of its sediment discharge during major flood events. Years may pass before the effects of this change in the discharge of the Tigris-Euphrates are manifested, however.

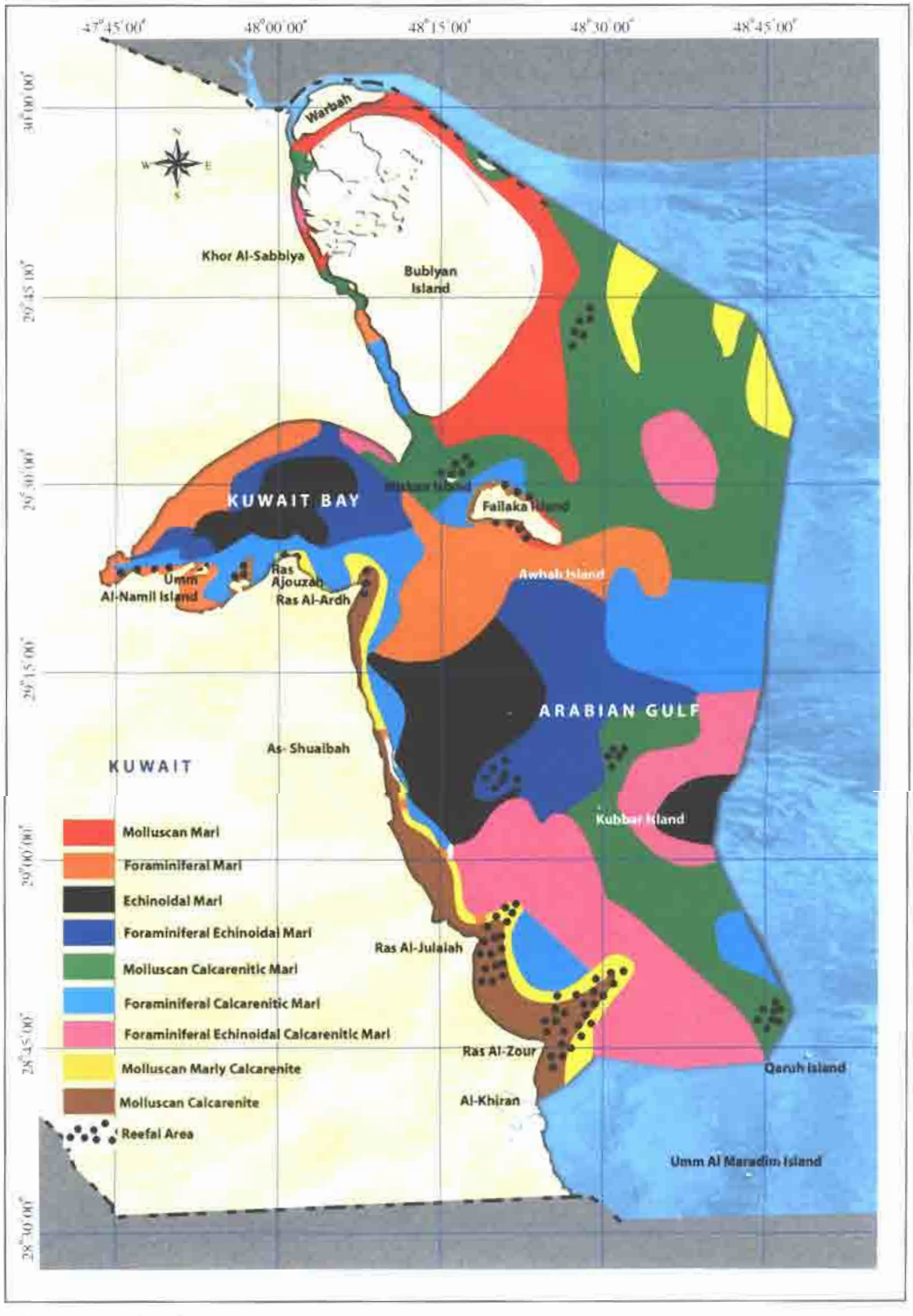


Fig. 38. Biolithofacies map of the marine bottom sediments off Kuwait.

Waves and Currents

The wave height in Kuwait's coastal zone is usually up to 2 m, with maximum values of 3 to 4 m during stormy conditions. In general, wave height decreases along the coastline from south to north, because of fetch limitation. The wave period ranges from 2 to 5 s over the year, with the prevailing wave periods being between 2 and 3 s (Samhan et al., 1987). The waves have a shorter wavelength when winds blow from the northwest compared with southeast winds (3-5 s period compared with 7-9 s period).

Tidal currents are the major source of water circulation in Kuwait's coastal areas. In Kuwait Bay, a weak counterclockwise circulation appears to prevail over most of the year. This circulation tends to reverse briefly in winter when southeasterly winds predominate. Kuwait Bay is large enough to also exhibit different circulation patterns simultaneously. Occassionally, currents show a net clockwise drift in the western part of the Bay, and a counterclockwise pattern in the eastern part (Dames and Moore, 1983). Tidal currents along Kuwait Bay's south coast to Ras Al-Ardh flow northerly parallel to the shoreline during the flood phase and southeasterly during the ebb tidal phase (Litherathy et al., 1986).

Current speeds are highest in Khor Al-Sabbiya, reaching up to 120 cm s^{-1}. Within Kuwait Bay, the highest speed was measured at the Bay's entrance, with current speed decreasing towards the western portion of the Bay, where it is usually <40 cm s^{-1} (Dames and More, 1983). Along the southern coast at a station offshore to Shuaibah, a maximum current speed of 53.5 cm s^{-1} was recorded in April 1983 during an 18-month study (Literathy et al., 1985).

Water Circulation and Sediment Transport

An anticlockwise circulation pattern exists along the western side of the Arabian Gulf, which includes Kuwait's territorial waters (Lardner et al., 1993; Reynolds, 1993). Local exceptions are found around the two headlands of Ras Al-Julaiah and Ras Al-Zour. Studies show a net southward mass displacement along the open coast south of Kuwait Bay, which joins with the main anticlockwise circulation pattern along the western side of the Arabian Gulf.

Three distinct coastal regions were identified for sediment movement and processes acting along the coast: (1) the current-dominated Khor Al-Sabbiya; (2) the dynamically sheltered Kuwait Bay; and (3) the wave-dominated southern coast. The relatively strong tidal currents along the Khor Al-Sabbiya channel are responsible for the high concentration of suspended sediment and high sediment transport through the channel (Al-Bakri et al., 1985). Total suspended solids in Khor Al-Sabbiya and around Bubiyan and Failaka Islands are about 10 times higher than those in offshore waters. The net sediment transport in Kuwait Bay (Fig. 39) is estimated to be rather modest, with deposition of suspended sediment on the low energy zones of the Bay. The net transport along the southern coastal region is northbound and restricted to the winter season. As a whole, the southern coastal region is believed to be an accretional environment, especially in the southern reaches and headlands. Limited areas along both sides of the headlands show erosional effects.

In general, the surface tidal currents in the offshore area show an ebb-dominant flow, which again agrees with the general counterclockwise circulation that characterizes the northwestern part of the Gulf.

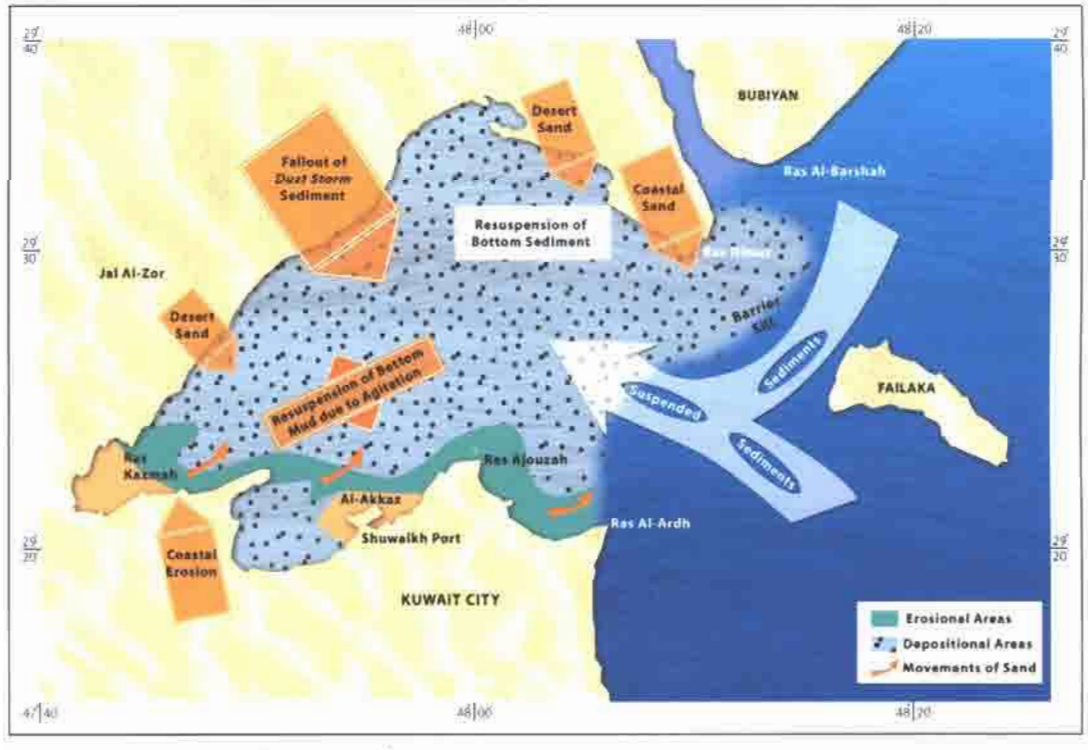
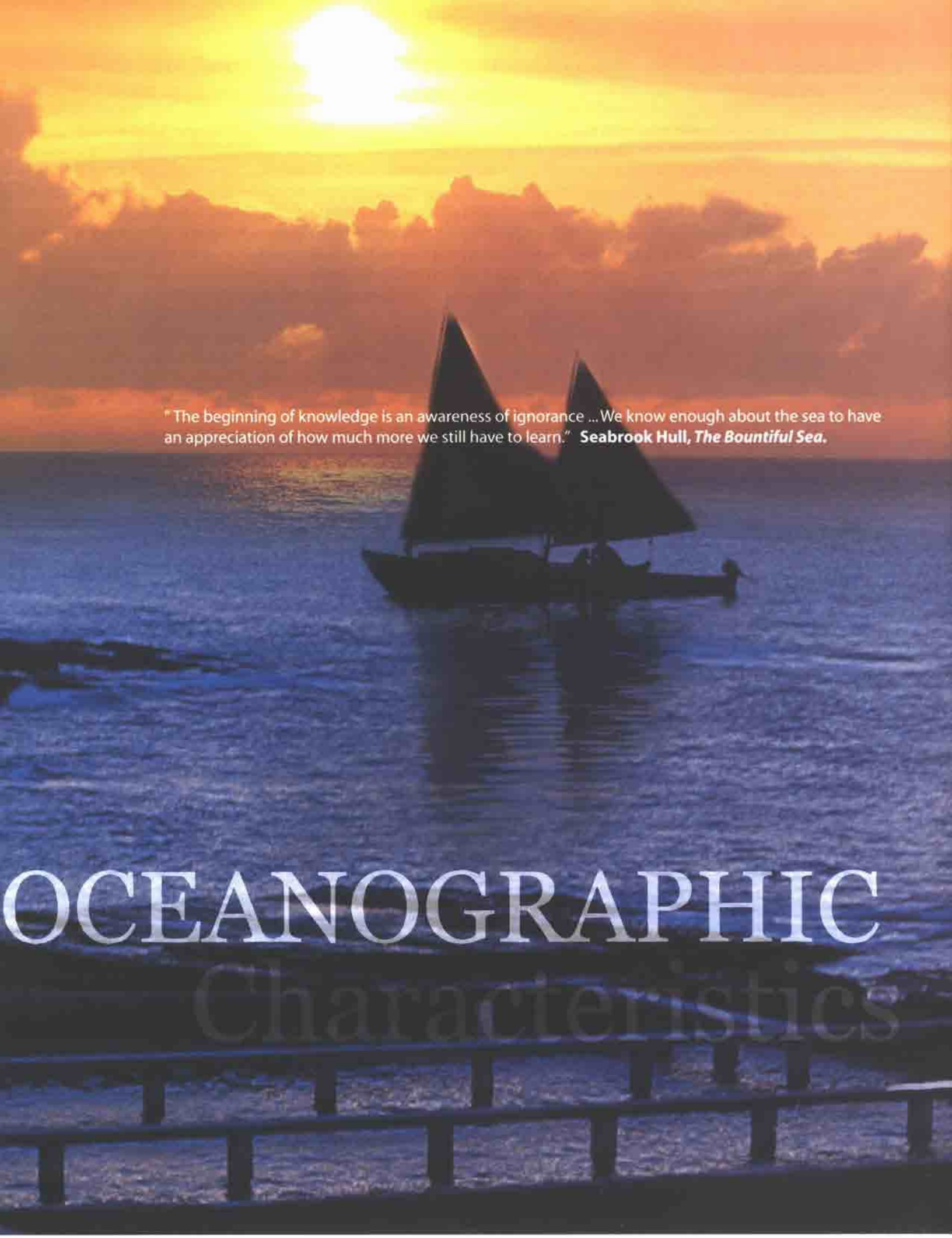


Fig. 39. Conceptual pattern of sediment transport in Kuwait Bay.



" The beginning of knowledge is an awareness of ignorance ... We know enough about the sea to have an appreciation of how much more we still have to learn." **Seabrook Hull, *The Bountiful Sea*.**

OCEANOGRAPHIC Characteristics



PHYSICO-CHEMICAL CHARACTERISTICS AND BIOLOGICAL OCEANOGRAPHY OF KUWAIT'S WATERS

Knowledge of the basic oceanographic characteristics of Kuwait's marine waters is essential in the planning of shoreline development projects, selecting locations of new power and desalination plants, construction of offshore structures and management of marine resources. The capacity of coastal waters to assimilate various pollutants is strongly influenced by the physical and chemical oceanography of the marine environment.

Most of the previous oceanographic studies in Kuwait's waters were confined to limited periods of the year or to specific localities, for example: Al-Attar and Ikenoue (1974); Jacob et al. (1981); Anderlini et al. (1982); Hunter (1982); Dames and Moore (1983); Khalaf et al. (1982, 1984); Al-Bakri et al. (1984); Michel et al. (1986); Houde et al. (1986); Al-Ghadban (1990); Al-Yamani et al. (1992, 1997a, b); Enomoto (1971); Kuronuma (1974); Anderlini (1979); Jacob and Zarba (1979); Lee et al. (1986); and Al-Ghadban and Salman (1993). The main emphasis in most marine surveys and studies has been on marine food resources, monitoring of water quality, pollution and pollutant transfers. A few limited physical, geological and biological studies have been conducted in the nearshore and intertidal areas, and around Failaka, Kubbar, Qaruh and Umm Al-Maradim islands.

The systematic collection of oceanographic data was initiated at the Mariculture and Fisheries Department at the Kuwait Institute for Scientific Research (KISR) in 1979, with descriptions of seasonal, spatial and diurnal variations in oceanographic conditions that were monitored during surveys and research studies. Monthly monitoring of oceanographic and water quality data has been carried out by the Environment Public Authority (previously referred to as the Environmental Protection Department of the Ministry of Health) since the 1970s (EPD, 1988, 1991, 1992).

Oceanographic information concerning certain aspects of Kuwait's waters, such as physical oceanographic processes, nutrient dynamics and recycling, and food chain dynamics, is both scanty and fragmentary. What is needed is a systematic investigation (time-series) of the seasonal physical, geochemical and biological characteristics of Kuwait's marine environment, as well as studies with an ecosystem-based approach.

Kuwait's waters are shallow, with a maximum depth of about 30 m (Fig. 40), and the water column is generally well mixed year-round. The waters are characterized by high biological productivity. The most important source of marine pollution in Kuwait, as is the case throughout the Arabian Gulf, is petroleum-related activities. The activities include loading oil tankers, discharge of bilge water, offshore drilling and production facilities, etc. Other major pollution sources are sewage discharges, industrial wastewater, atmospheric fallout, including emissions from power generation stations and oil refineries, and thermal pollution from power generation or industrial processes. Some of the pollutants reported in the marine environment are mercury, lead, chorinated and petroleum hydrocarbons and fertilizers (Al-Yamani et al., 2000).

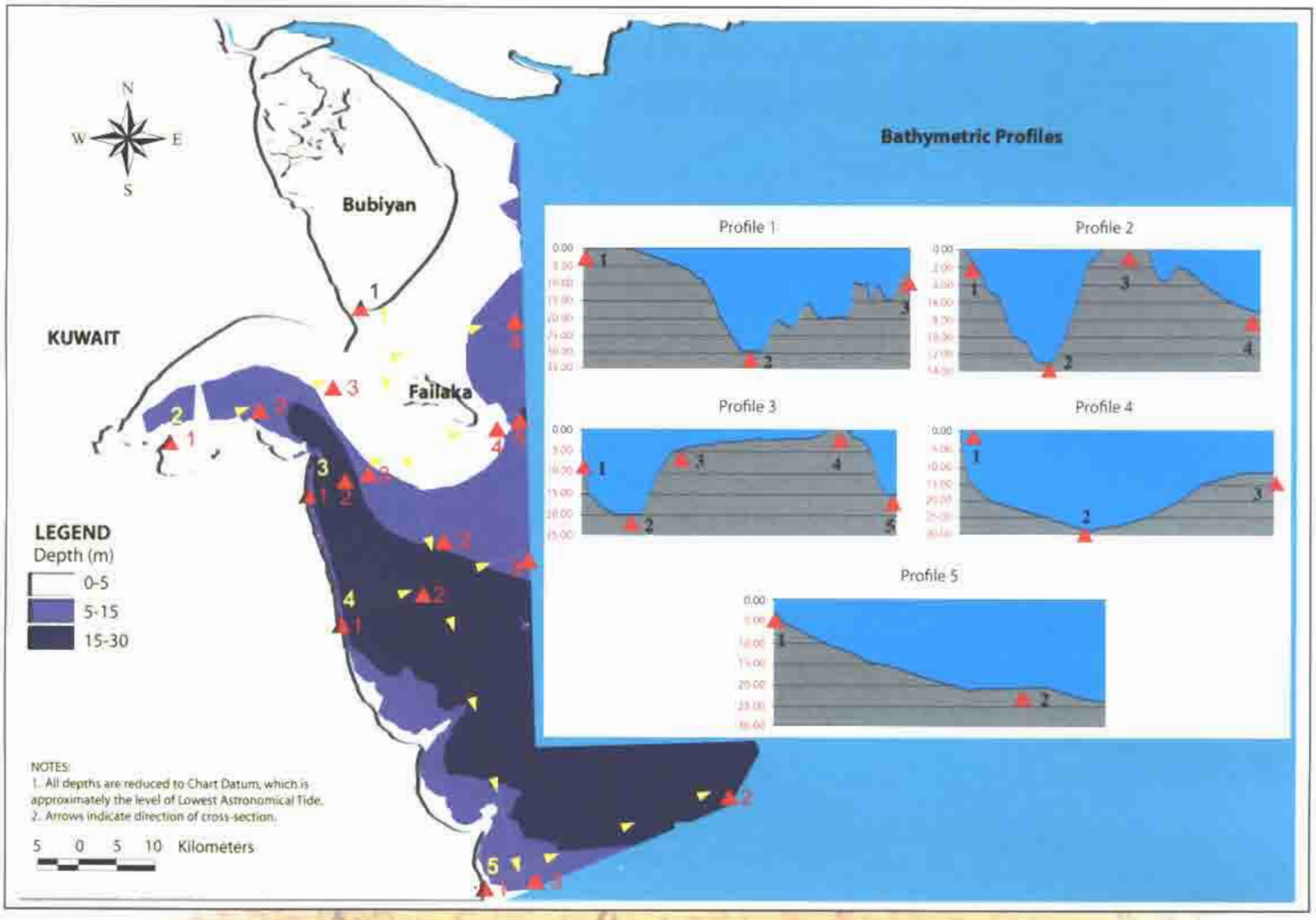


Fig. 40. Bathymetric profiles of Kuwait's waters.





Map showing locations of Kuwait's main coastal cities, ports (Mina) and islands.

Physical Characteristics

The temporal, spatial and vertical distributions of key physical variables are described below. The missing data for specific dates in the graphs and maps below indicate that no sampling was conducted on these dates.

Seawater Temperature.

The mean annual temperature of Kuwait's waters is 23.8 °C. There is a predictable summer-winter difference with the highest mean temperatures recorded in July and August (30.5 °C), and the lowest mean temperature recorded in January and February (14 °C) (Figs. 41 and 42). The lowest seawater

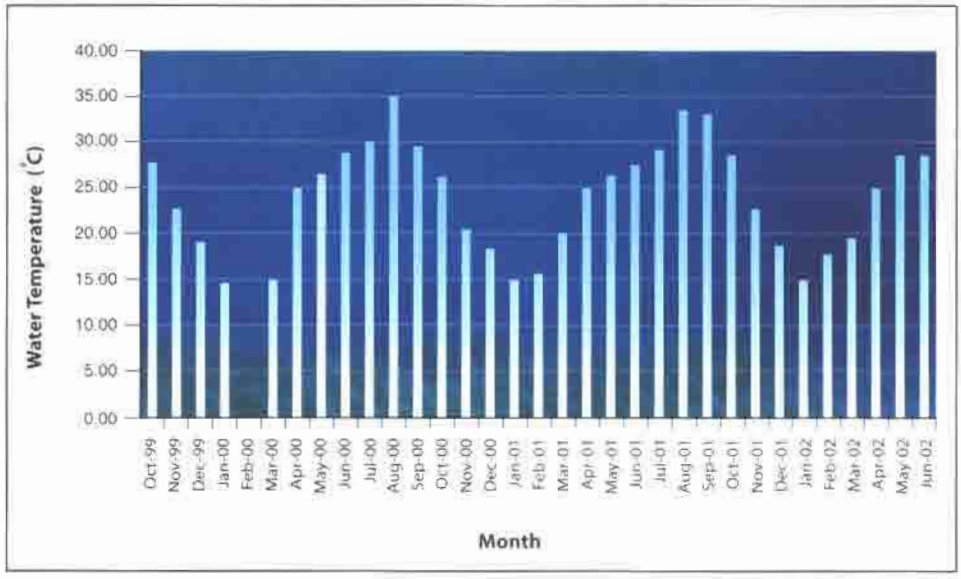


Fig. 41. Temporal variability of mean seawater temperature in Kuwait's waters

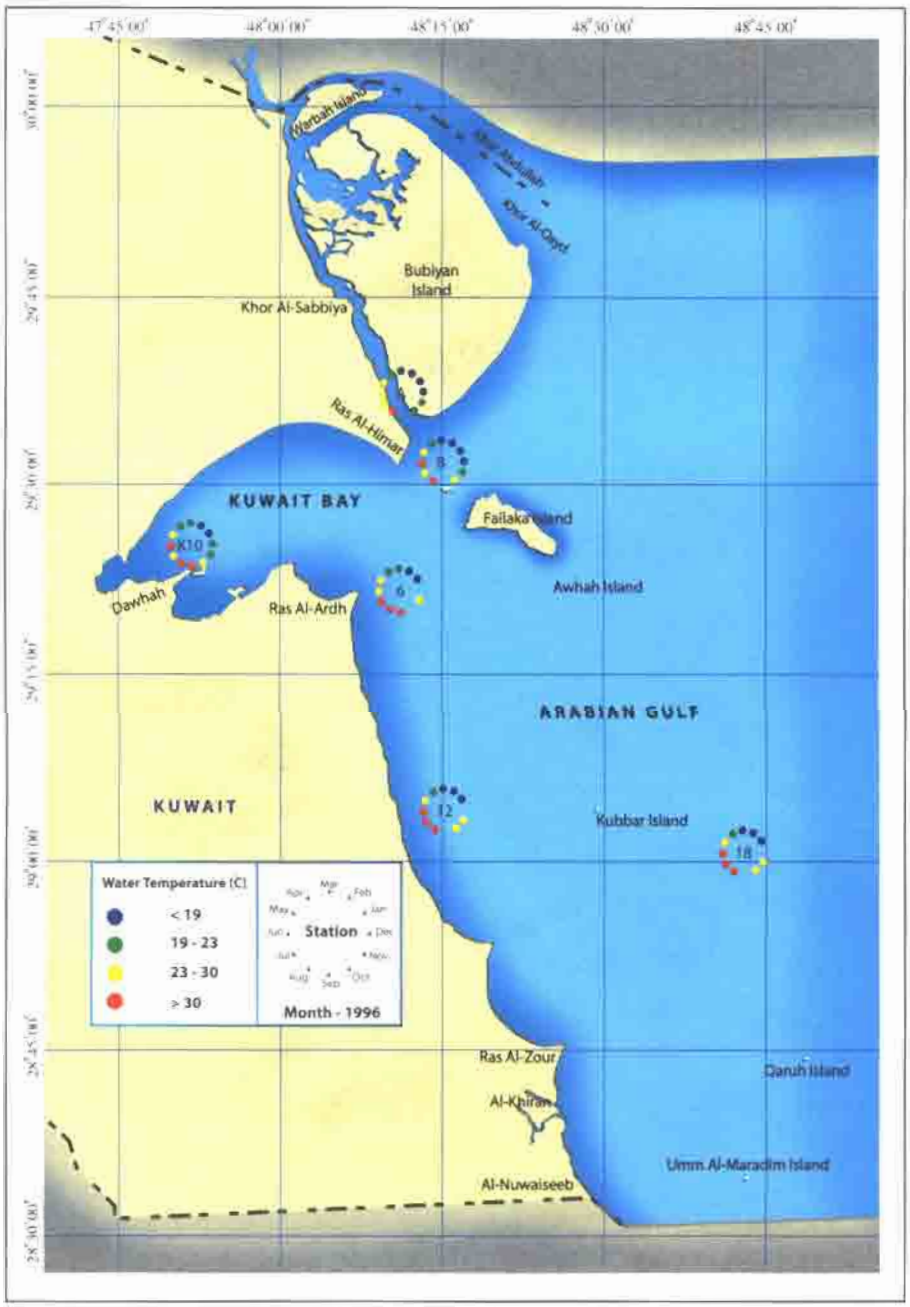


Fig. 42. Temporal and spatial variability of mean seawater temperature in 1996 in Kuwait's waters.

temperature recorded for Kuwait's waters was 11.9 °C in Kuwait Bay in January 1993, and the highest seawater temperature recorded was 36 °C in Kuwait Bay in August 2001. The minimum seawater temperature recorded in Khor Al-Sabbiya waters was 10 °C in December 1984 (Shunbo et al., 1986). Therefore, the seasonal difference in surface seawater temperature can exceed 25 °C. In general, there is a temperature increase during the months of March through September and then a decrease thereafter, with minimum temperatures in January and February. Bottom waters exhibit a similar pattern of seasonal variations in temperature as does the surface waters.

There is a slight spatial variation in temperature among different locations in Kuwait's waters (Fig. 43). The range of mean temperatures for the different sampled locations from the northern area, including Khor Al-Sabbiya and Kuwait Bay, to the south, including Kubbar waters and Al-Khiran, is 22.4-25.6 °C, but the variabilty is not statistically significant. Kuwait's northern waters are generally cooler than southern and offshore waters, especially during winter and spring.

Temporary vertical stratification of temperature occurs at deeper stations (> 12 m) outside Kuwait Bay and at the southernmost deeper stations, but only in the spring and summer (March to September). During the other months of the year, however, the water column is usually well mixed. Vertical temperature

gradients of 6 °C in June and 1.3 °C in September 1985 were recorded at a monitoring station off Ras Al-Ardh/Salmiyah (Literathy et al., 1986). Lee et al. (1986) reported vertical stratification during March and April, with a temperature difference of 2.1 °C and 1.7 °C, respectively, in addition to a thermocline during July in deeper waters. Al-Rifaie et al. (2002) reported vertical stratification with depth during March and May at stations deeper than 12 m depth, with a temperature difference between surface and bottom layers of 6.6 °C. A temporary temperature inversion occurs at the northern stations in Sabbiya and northwestern Failaka Island during cold periods in February.

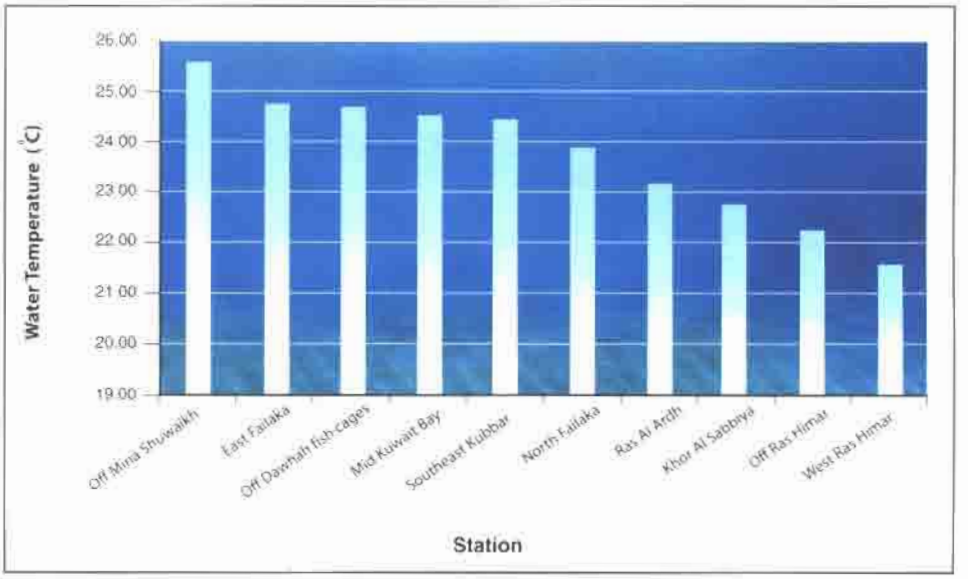


Fig. 43. Spatial variability of mean seawater temperature in Kuwait's waters (2000 - 2002).

Salinity. Salinity fluctuates in Kuwait's waters. Two factors determine the annual variation of salinity in Kuwait's waters: the inflow of fresh water from the Shatt Al-Arab River caused by heavy rainfall during the winter, and melting of snow in Turkey, Syria, Iraq and Iran during the spring period; and the intensive evaporation of seawater during the hot summer months from May to October (Lee et al., 1985). Local rainfall and land runoff during the winter months (December-February) might also affect the surface salinity of Kuwait's waters (Lee et al., 1985 a, b).

There is a general salinity decrease from December to June and an increase in the following months (Figs. 44 and 45). Anderlini et al. (1982) reported a salinity range between 37 and 50 psu in Kuwait Bay during a 12 month study in 1981, and Literathy et al. (1986) reported a minimum salinity of 38.5 psu at an offshore Shuaibah station. Shunbo et al. (1986) recorded a low salinity value in Khor Al-Sabbiya waters of 33 psu. The mean salinity of Kuwait's waters was 39.6 psu for the period prior to 1993, with a range of means of 37.6-41.1 psu (minimum record of 35.3 psu and maximum record of 43.9 psu). However, following 1993, a drop in mean salinity of Kuwait's waters was recorded due to fresh water flowing from Iraq's man-made Third River into the Khor Al-Sabbiya waters. The Third River flows at varying rates directly into Khor Al-Zubair and then into Khor Al-Sabbiya.

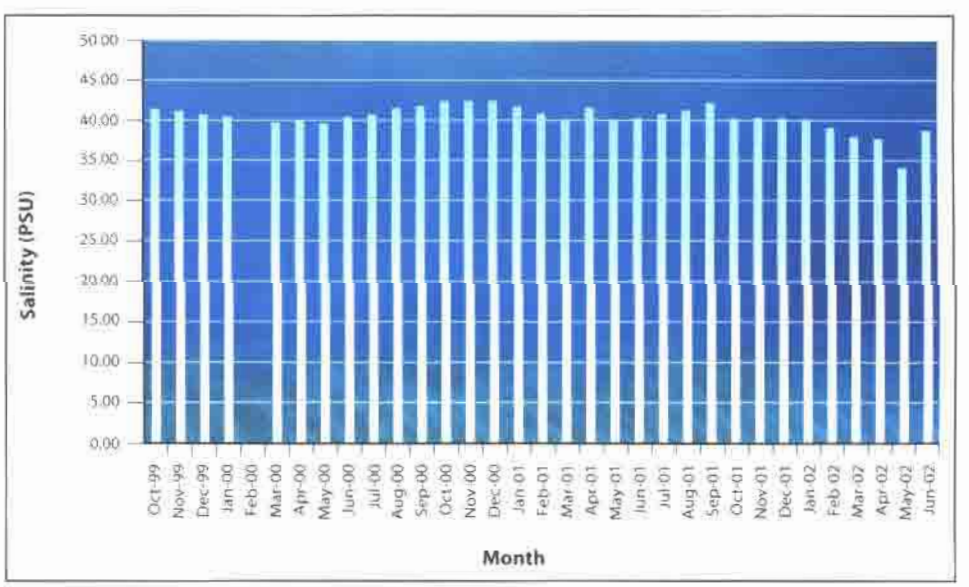


Fig. 44. Temporal variability in mean salinity in Kuwait's waters.

During 1995-1996, the mean salinity of Kuwait's waters dropped to 34.7 psu (minimum record of 17.3 psu in Khor Al-Sabbiya). During1996-1997, mean salinity for Kuwait's waters was 36.6 psu, with a minimum value recorded of 22.9 psu in Khor Al-Sabbiya (February 1997) (Al-Yamani et al., 1997a,b). The latest salinity values during 1999-2002 indicate a mean salinity of 41.6 psu, with a minimum of 33.5 psu in Khor Al-Sabbiya, indicating a rise in salinity for Kuwait's waters compared to the 1995-1998 period.

There is a clear spatial distribution trend of salinity (Fig. 46), with lowest salinities occurring in the waters of Khor Al-Sabbiya and the northern stations due to the diluting influence of the fresh water inflow, and higher salinities occurring in Kuwait Bay and the southern most stations. There is an overall trend of higher salinity in the summer and fall, and lower salinity in the winter and spring. The salinity generally starts dropping around December, and then fluctuates at the lower levels throughout the spring as river and land runoff fluctuate, with minimum salinities being more often observed in May.

The vertical distribution of salinity shows uniform values during most of the months, whereas, from March to June, a slight salinity stratification is observed. Lower salinity values are recorded at the surface layer and higher salinity values at the bottom. Vertical stratification is more prominent at the deeper stations toward the south, with a weak halocline observed from February to July in some years. The development of this

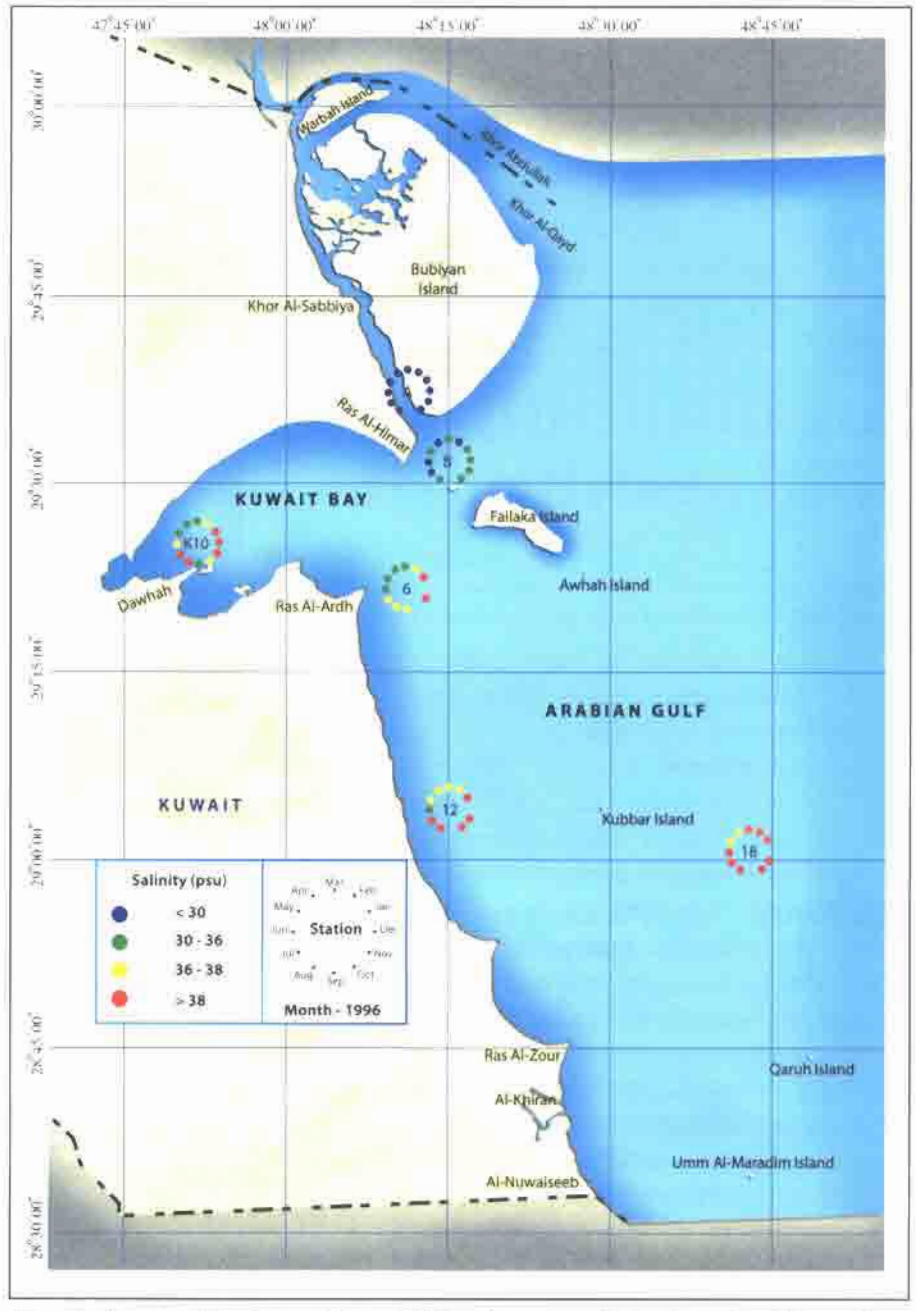


Fig. 45. Temporal and spatial variability of mean salinity in 1996 of Kuwait's waters.

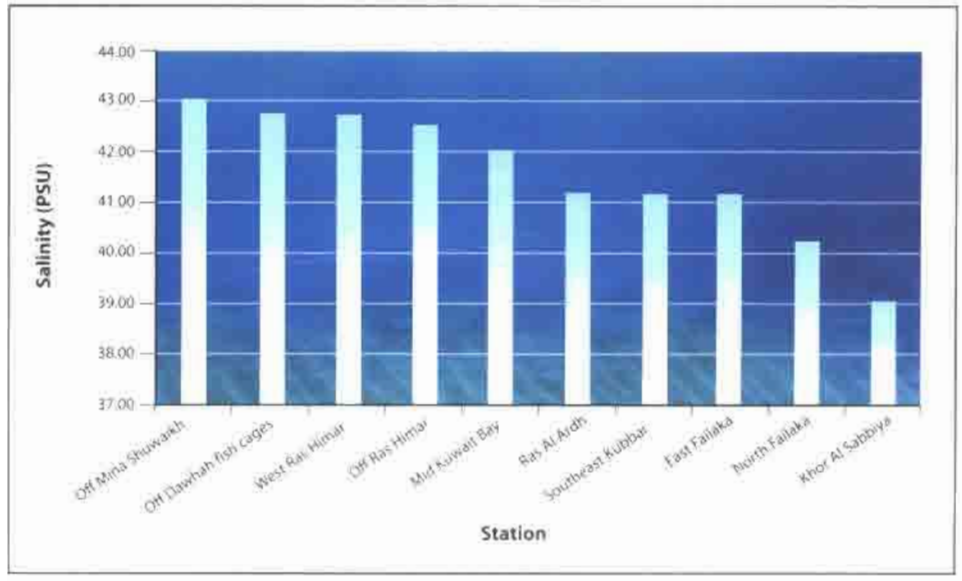


Fig. 46. Temporal variability in mean salinity in Kuwait's waters (2000 - 2002).

halocline is governed by the depth of the locality, seasonal variability in evaporation rates and the mass influx of fresh water from the north, especially at the stations affected by the fresh water discharge. Lee et al. (1986) reported a vertical salinity difference of 6.29 psu in May, and Al-Rifaie et al. (2002) reported salinity changes with depth during March and May, with a water column difference of 4.94 psu in May 1997. Diurnal variations in salinity are negligible in the open waters of Kuwait; however, they may be considerable in shallow coastal areas that are influenced by the tide.

Bio-optical Properties. There is little information on the seasonal variability in the bio-optical characteristics of the water column in the waters of Kuwait. The two basic processes that alter the underwater distribution of light, are absorption (change of light energy into other forms of energy) and scattering (change in direction of light without loss of energy). The attenuation of light in the ocean and seas is defined as the sum of absorption and scattering.

Transparency. Transparency increases from inshore to offshore waters and from the northern waters of Khor Al-Sabbiya to the southern waters of Kuwait.

Secchi disk transparency depths in Kuwait's waters range from 0.1 m in Khor Al-Sabbiyah, 0.45-4 m in Kuwait Bay and 16.5 m in the southern offshore waters.

Turbidity. The mean turbidity value for Kuwait's waters is 32.6 NTU, with a minimum of 0.1 NTU and maximum of 458.1 NTU. Turbidity is extremely high in Khor Al-Sabbiya (mean 150 NTU, range of 30.3- 458.1 NTU), but it drops dramatically toward the south (mean 5.7 NTU, range of 4.4- 10.7 NTU) (Figs. 47 - 49). The high turbidity in Khor Al-Sabbiya waters is due to the shallowness, effect of wind and tidal currents, nature of the seabed, and discharges from the Shatt Al-Arab (Al-Ghadban and Salman, 1993) and the Third River. Turbidity is relatively low in Kuwait Bay (mean 11 NTU, range of 5.0- 40 NTU), but it increases toward the northern entrance of the Bay (Al- Yamani et al., 1997b). Light limitation in the waters of Khor Al-Sabbiya is due to high turbidity levels, and results in reduced phytoplankton biomass.

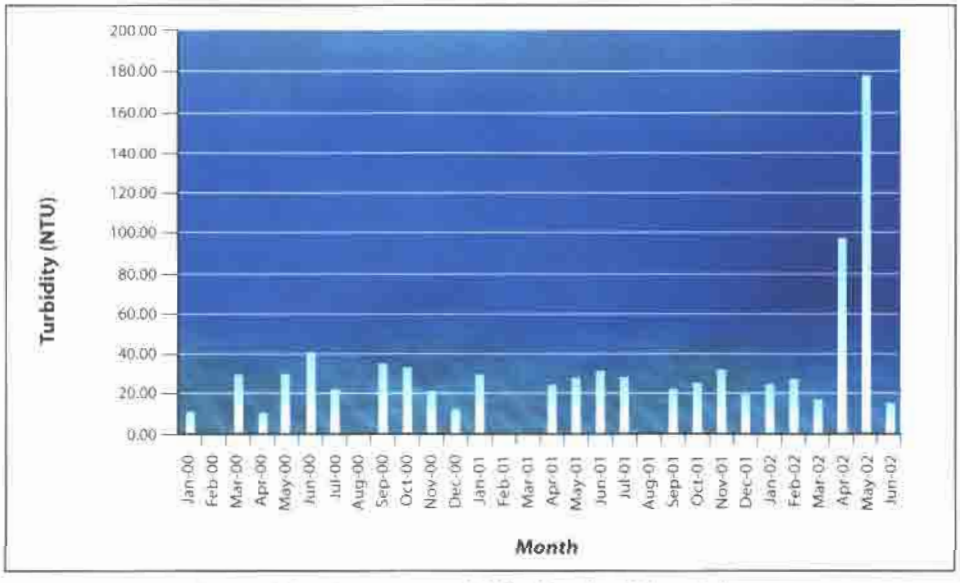


Fig. 47. Temporal variability in mean turbidity levels of Kuwait's waters.

Bio-optical oceanography also involves measurement of chlorophyll-*a*, primary production, phytoplankton community, concentration of other particulate materials as well as concentration of colored components of dissolved organic matter (CDOM). The above variables (except for CDOM with no available measurement) are discussed under phytoplankton. Total suspended solids is discussed below.

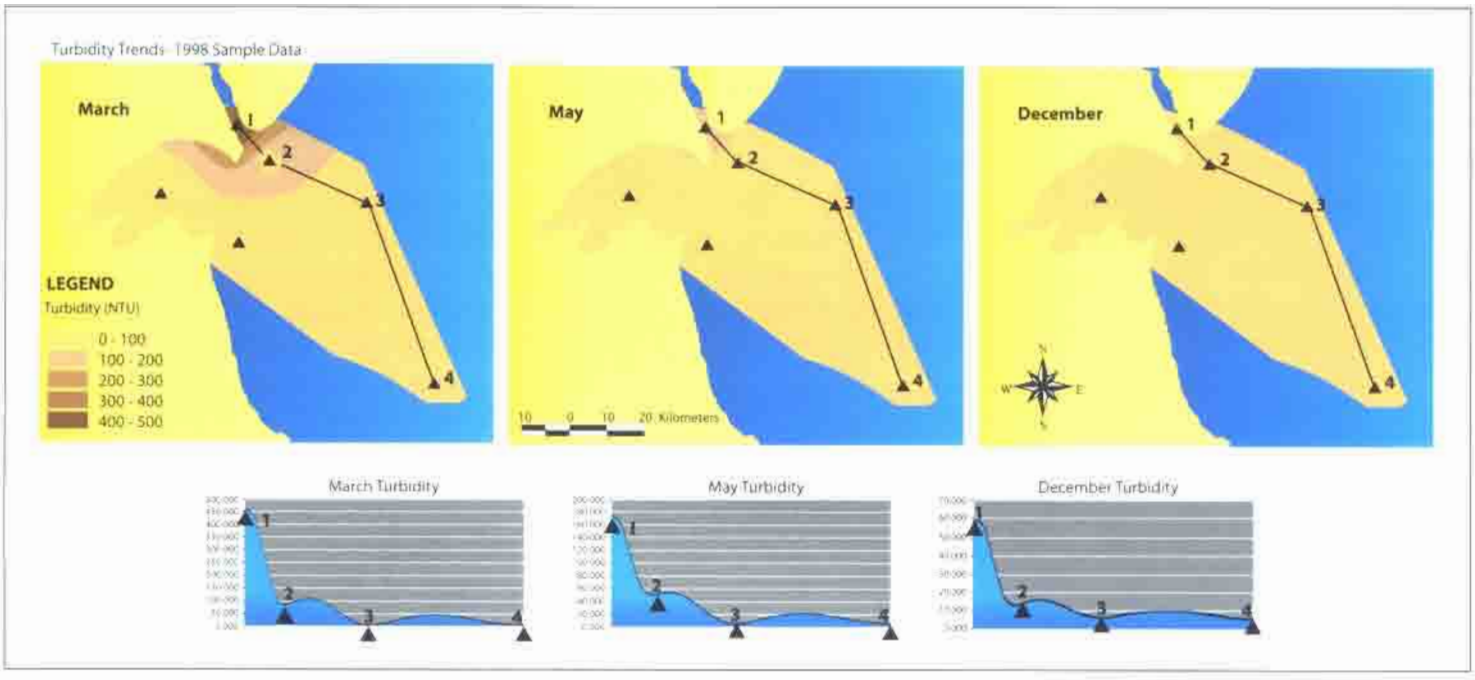


Fig. 49. Temporal and spatial variability in mean turbidity levels of Kuwait's waters

Total Suspended Solids. Mean concentration of total suspended solids (TSS) in Kuwait's waters (excluding the northern waters of Khor Al-Sabbiya and northern Failaka) for the period of 1985-1993 was 11.3 mg/l, with a maximum of 27.6 mg/l recorded in February in Kuwait Bay. The minimum value of 0.3 mg/l was found in the southern offshore waters while high values > 40 mg/l were recorded in the inshore turbid waters of Kuwait. The range of TSS during 2000-2003 including Khor Al-Sabbiya waters is 5-510 mg/l. Spatial and temporal variability in the concentration of suspended solids exists in Kuwait's waters (Al-Yamani et al., 1997a).

Chemical Characteristics

The temporal, spatial and vertical distribution of the key chemical variables of Kuwait's waters are described here. The missing data for specific dates in the graphs and maps below indicate that no sampling was conducted on these dates.

pH. Mean pH of Kuwait's waters is 8.2 (range of 7.6-9.0). In general, the spatial variation (Fig. 50) in pH values is not statistically significant, indicating the high buffering capacity of these waters (Dames and Moore, 1983). Temporal variability of pH (Fig. 51) has been observed in Kuwait's waters, but with no definite seasonal trend. In general, the main

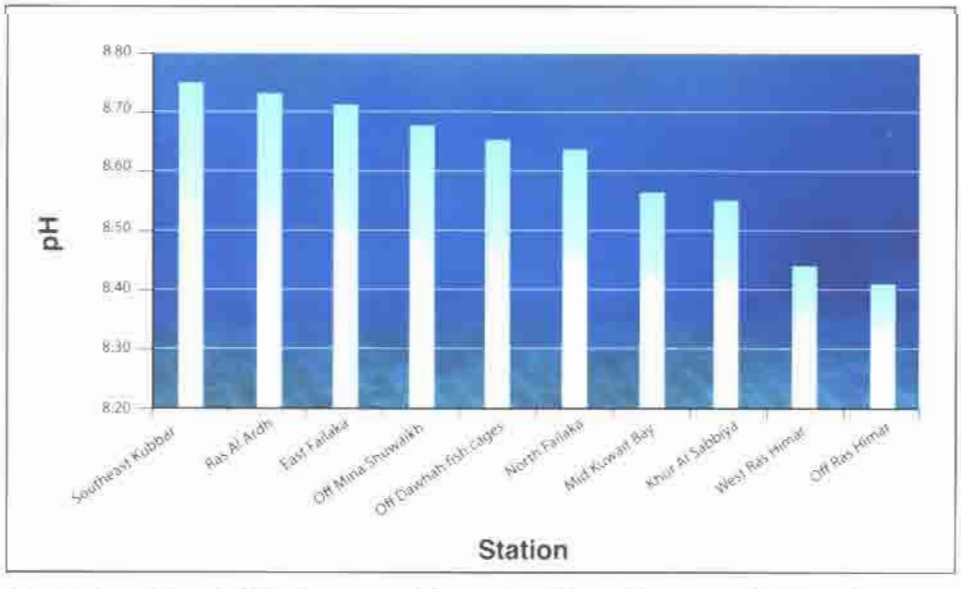


Fig. 50. Spatial variability in mean pH records of Kuwait's waters (2000 - 2002).

reasons for pH variability include input of sewage and chemical discharges, high primary productivity rates, or high decomposition rates. There are no significant differences in the pH values with depth.

Alkalinity. The mean alkalinity of Kuwait's waters for the period of 1985-1993 was 143.8 ppm, with a minimum of 114.1 and a maximum of 171.0 (Al-Yamani et al., 1997a).

Dissolved Oxygen. Kuwait's waters are generally oxygen-rich, and the dissolved oxygen levels vary according to temperature and salinity, depth, time of day, wind, waves, currents, atmospheric pressure and biological productivity. The mean oxygen concentration is typically 4.3 ml/l (6.1 mg/l), with a wide range from 1.44 ml/l (2.1 mg/l) recorded in the bottom layer in June in the NW Failaka waters to 14.5 ml/l (20.7 mg/l) recorded in surface layer in October 1999 in highly productive bloom waters in Kuwait Bay. Dissolved oxygen is usually consumed in the spring time in Kuwait Bay following the decay of phytoplankton blooms and the biodegradation of the organic load, and in the summer along the southern shoreline of Kuwait Bay. Hence, high dissolved oxygen concentrations and oversaturation (160% saturation) are associated with peak primary production rates, and low values and undersaturation (38% saturation) are associated with organic matter degradation or low mixing of the water column, especially during the hot and calm summer months.

In general, there is no significant concentration difference of oxygen with depth since the waters are shallow and well mixed throughout the year. Spatial and seasonal distributions of dissolved oxygen concentrations for the years 1996, 1998 and 2000-2002 are displayed in (Figs. 52-55).

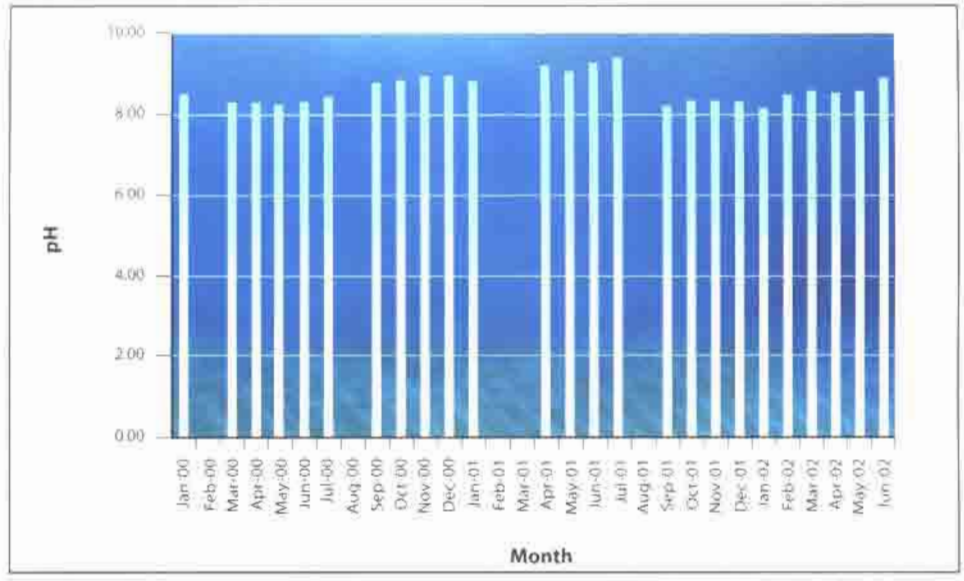


Fig. 51. Temporal variability in mean pH records of Kuwait's waters.

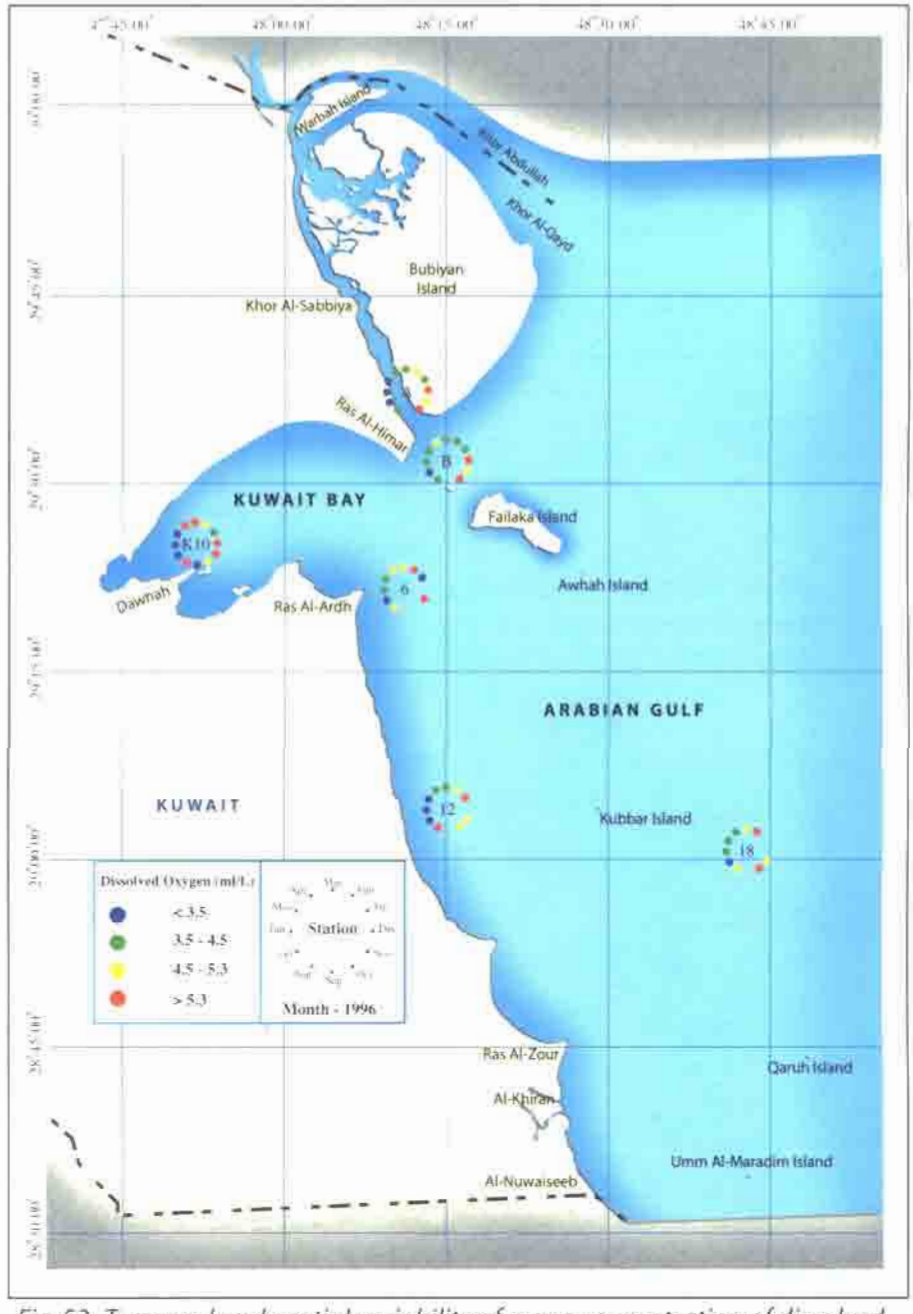


Fig. 52. Temporal and spatial variability of mean concentration of dissolved oxygen of Kuwait's waters in 1996.

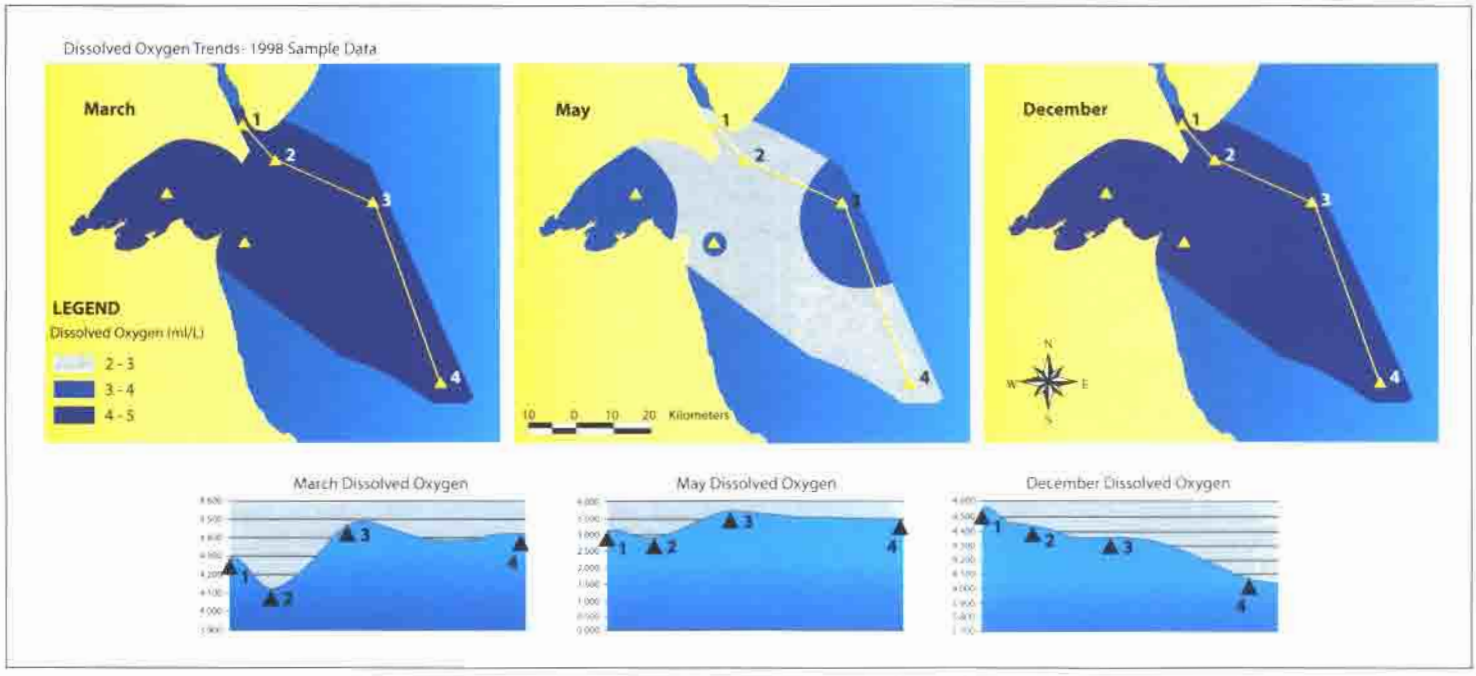


Fig. 53. Temporal and spatial variability in mean dissolved oxygen concentration of Kuwait's waters in 1998.

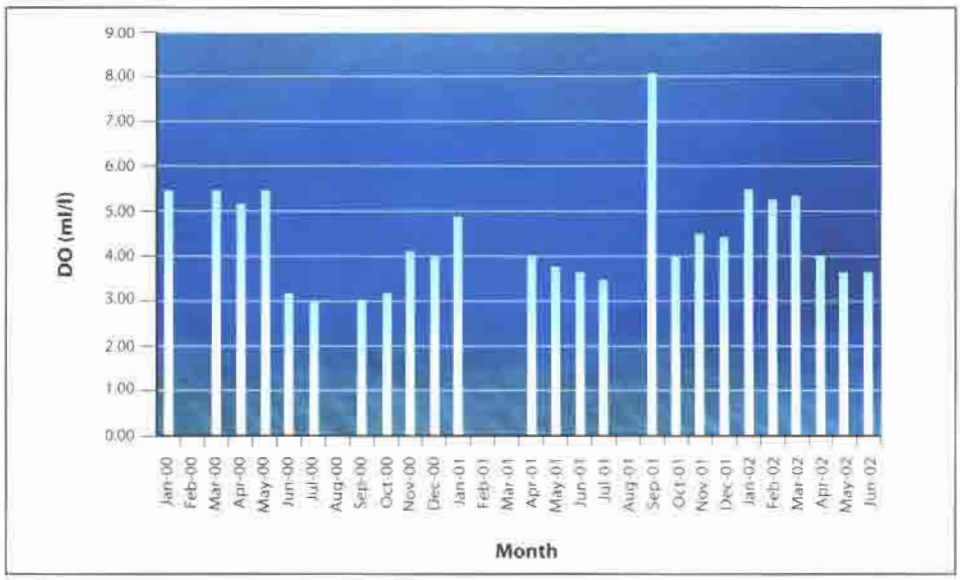


Fig. 54. Temporal variability in mean dissolved oxygen (DO) concentration of Kuwait's waters.

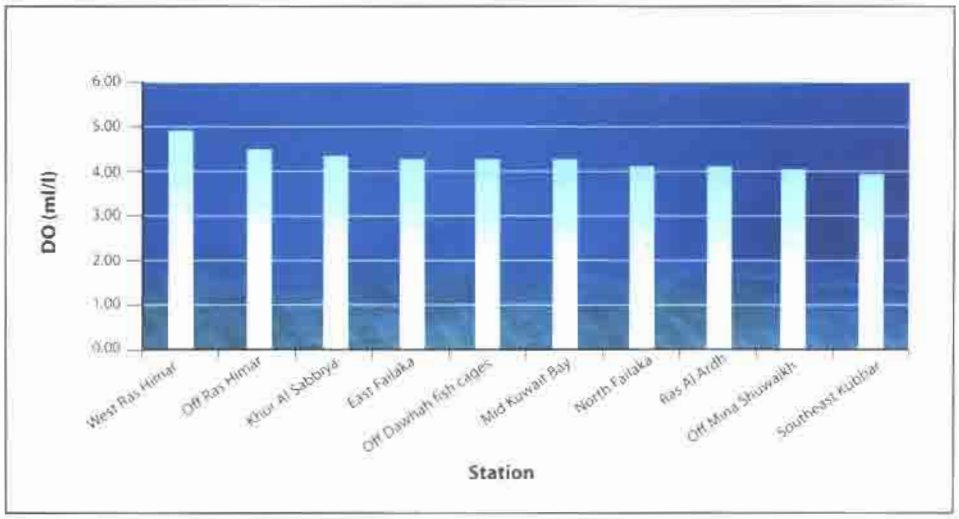
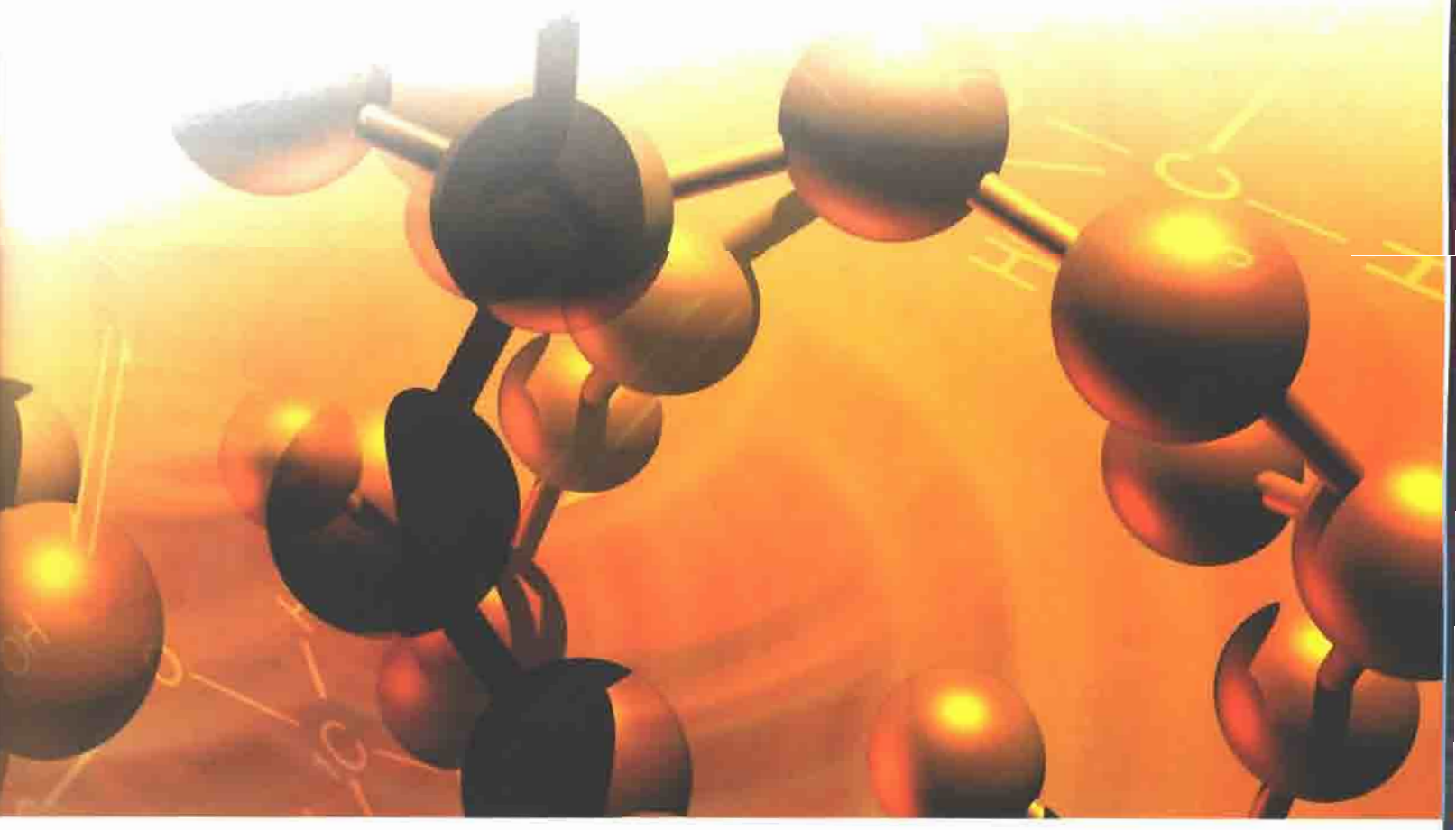


Fig. 55. Spatial variability in mean dissolved oxygen concentration of Kuwait's waters (2000 - 2002).

Inorganic Nutrients. Of the many environmental factors that influence primary production, the main regulatory factors are the light field and the rate of nutrient input to the primary producers. Kuwait's waters are nutrient-rich, and nutrient inputs are mainly from the Shatt Al-Arab River (and recently the Third River), sewage discharge, land runoff and, possibly, dust from duststorms (Subba Rao and Al-Yamani, 1999). Nutrient concentration in nearshore waters and Kuwait Bay are higher than those in the offshore waters. The nutrient data show a dramatic decline in the concentrations of nitrate, phosphate, and silicate from the Khor Al-Sabbiya to the stations in the south, but a less pronounced decline was observed for ammonia (Al-Yamani et al., 1997b). Phosphate and silicate concentrations in Kuwait Bay are similar to those at the stations south of Failakah Island, but they occur in higher concentrations in the inner waters of Kuwait Bay than in the middle area or outside the Bay entrance (Ras Al-Ardh). Total inorganic nitrogen is roughly the same throughout Kuwait Bay, but is mostly in the form of ammonia in the inner Bay waters and approximately in the form of ammonia and nitrate (equal amounts) toward the entrance of the Bay. Fresh water from the north is a major source of nitrogen for Kuwait's waters and the northern Arabian Gulf.

Very high nutrient levels were recorded in seawater in close proximity to a sewage outfall off Salam Beach in Shuwaikh during the period of 22 August - 17 September 2001. Water quality values are tabulated below:

Variable	Minimum- Maximum Values
Temperature	31.50-32.40° C
Salinity	15.90-17.10 psu
Chlorophyll-a	6.4-25.0 µg/l
NH_3 (ammonium)	2.7-24.6 µg-at/l or N-NH_3 µmol/l
NO_2 (nitrite)	16.3-35.5 µg-at/l or N-NO_2 µmol/l
NO_3 (nitrate)	785.3- 1574.9 µg-at/l or N-NO_3 µmol/l
PO_4 (phosphate)	4.36-38.75 µg-at/l or P-PO_4 µmol/l
SiO_3 (silicate)	220.7- 572.4 µg-at/l or Si-SiO_3 µmol/l



Ammonia. Ammonium is produced by the decomposition of organic nitrogen-containing compounds. The mean concentration of ammonium in Kuwait's waters is 1.38 µg-at/l, with a typical range of 0.0 µg-at/ l (undetectable concentration) to 30.31 µg-at/l. The high value was recorded from a station in Kuwait Bay close to a sewage outlet. Ammonia concentrations are extremely episodic, but most of the pulses are in the spring. Spatial and seasonal distributions of ammonium concentrations for the years 1996, 1998 and 2000-2002 are displayed in Figs. 56-59.

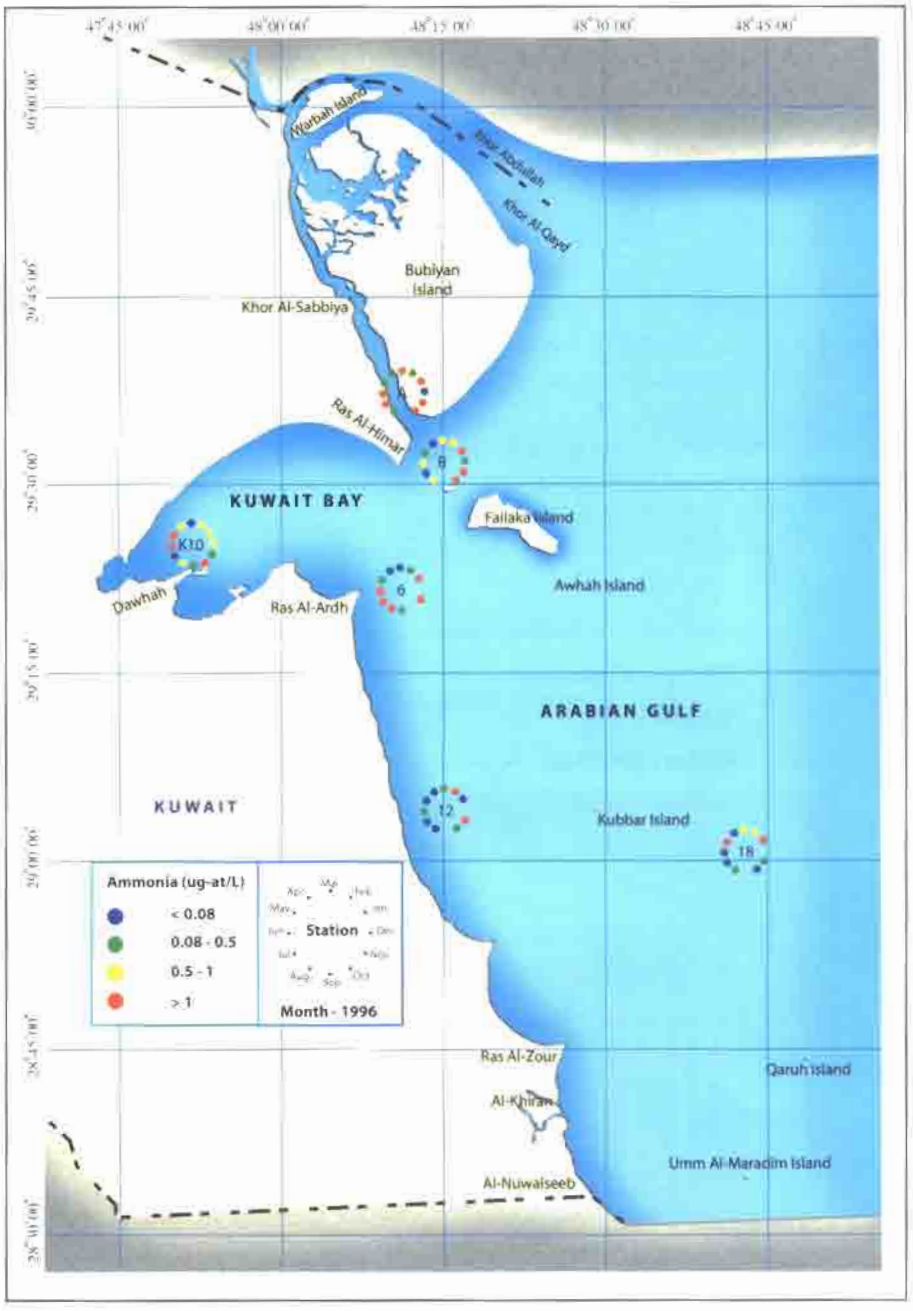


Fig. 56. Temporal and spatial variability of mean concentration of ammonia in 1996 in Kuwait's waters.

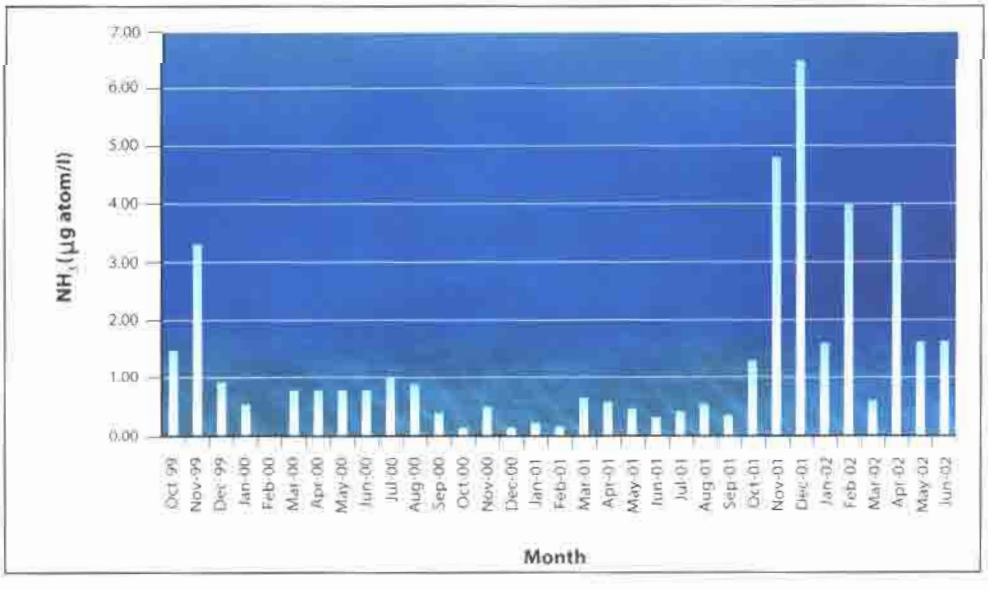


Fig. 57. Temporal variability in mean ammonium concentration of Kuwait's waters.

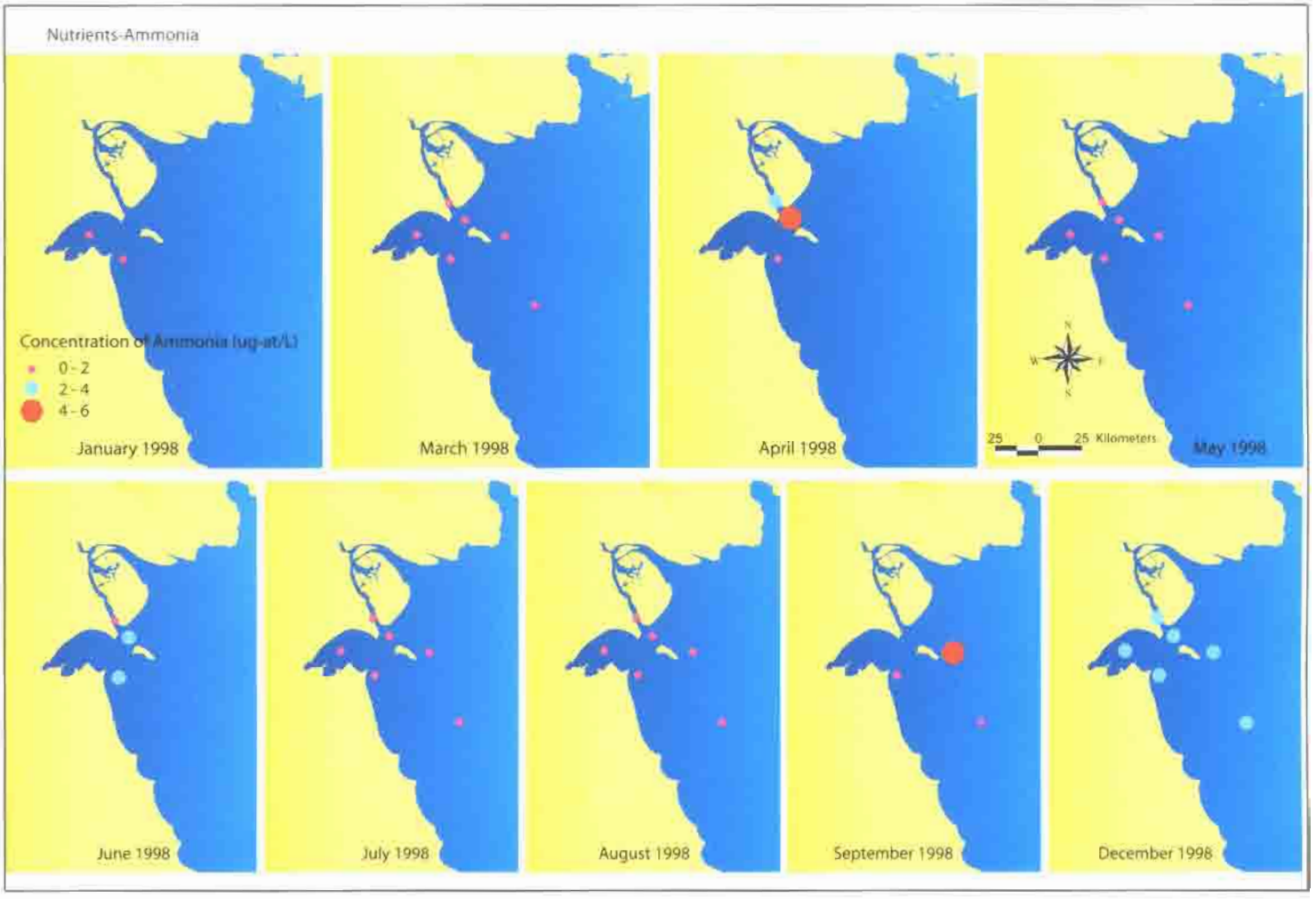


Fig. 58. Temporal and spatial variability of mean concentration of ammonia in 1998 in Kuwait's waters.

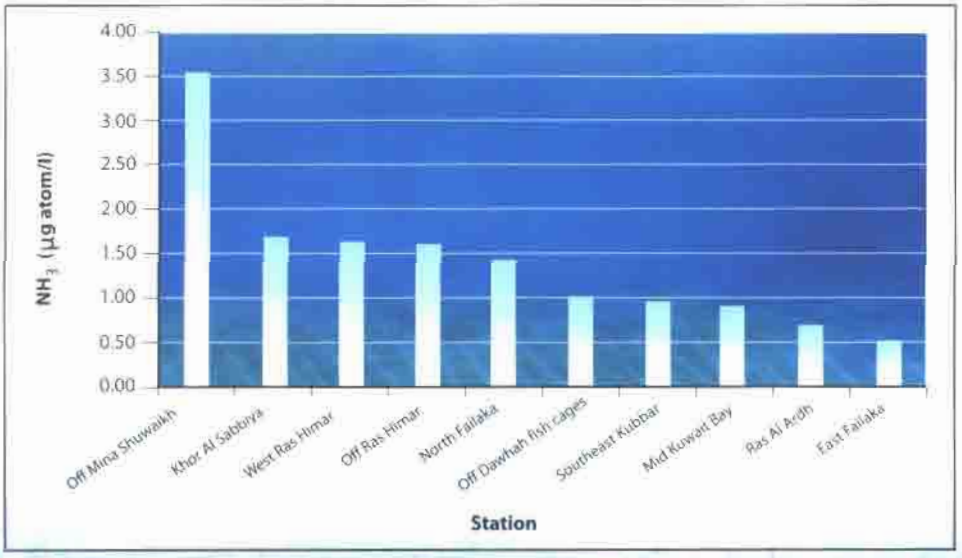


Fig. 59. Spatial variability in mean ammonium concentration of Kuwait's waters (2000 - 2002).

Nitrites. Nitrite is an intermediate form in the oxidation of ammonium nitrogen, and it is found in abundance in wastewater treatment plants. Mean nitrite concentration in Kuwait's waters is 0.33 µg-at/l, with a range of 0.0 µg-at/l (undetectable concentration) to 4.78 µg-at/l. Spatial and seasonal distributions of nitrite concentrations for the years 1996, 1998 and 2000-2002 are displayed in Figs. 60-63.

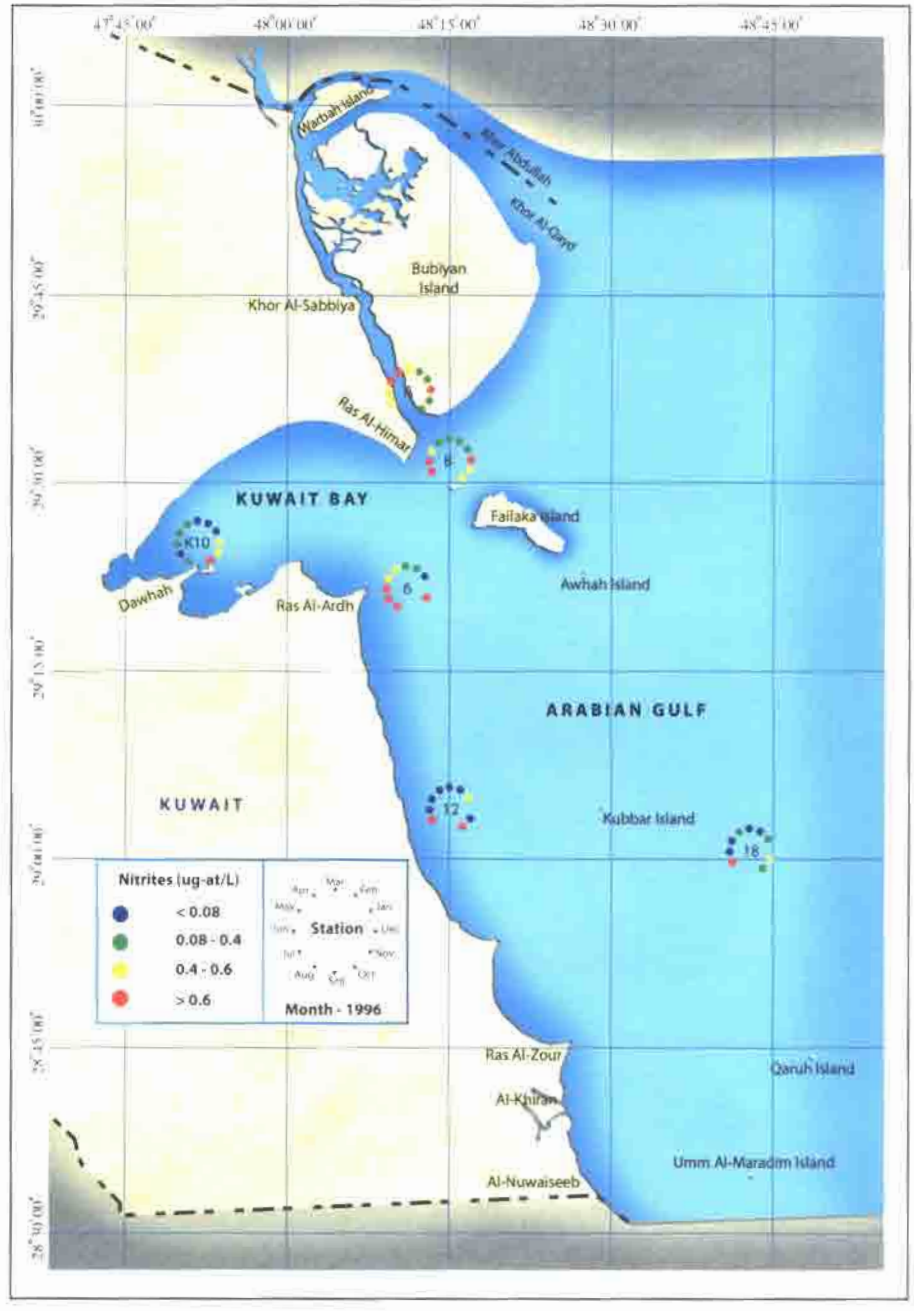


Fig. 60. Spatial and temporal variability in the concentration of nitrite in 1996 in Kuwait's waters.

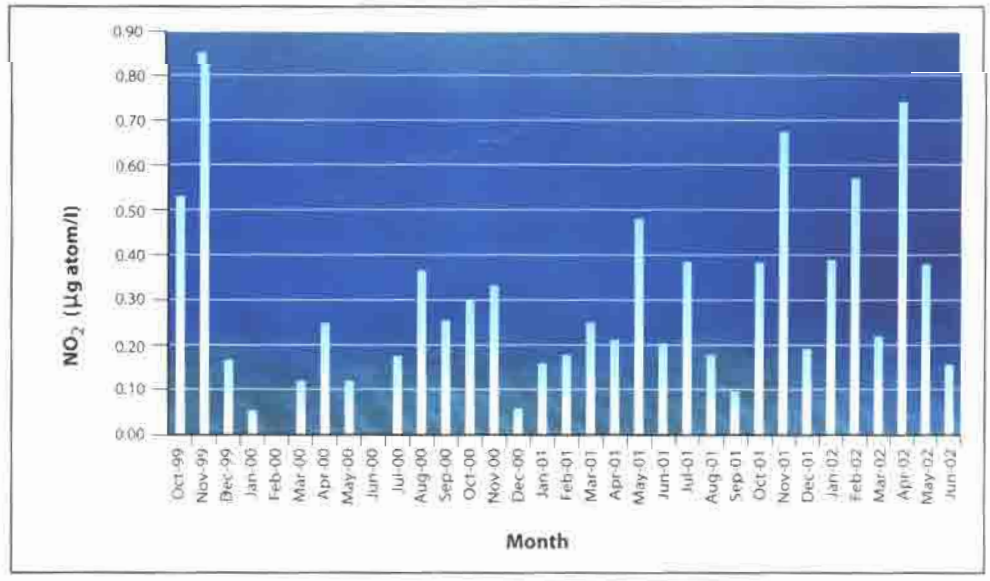


Fig. 61. Temporal variability of nitrite concentration in Kuwait's waters.

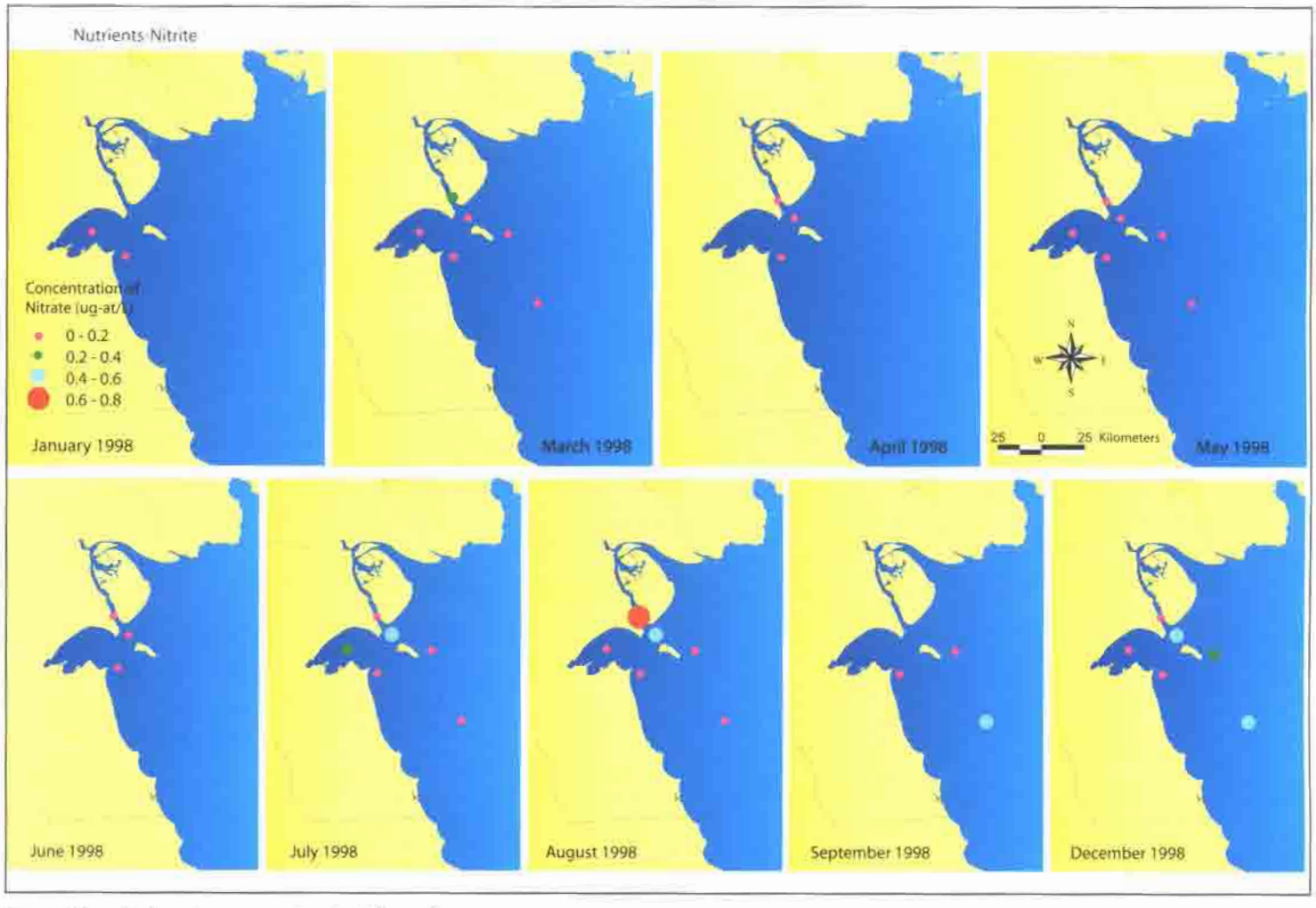


Fig. 62. Spatial and temporal variability of mean nitrite concentration in 1998 in Kuwait's waters.

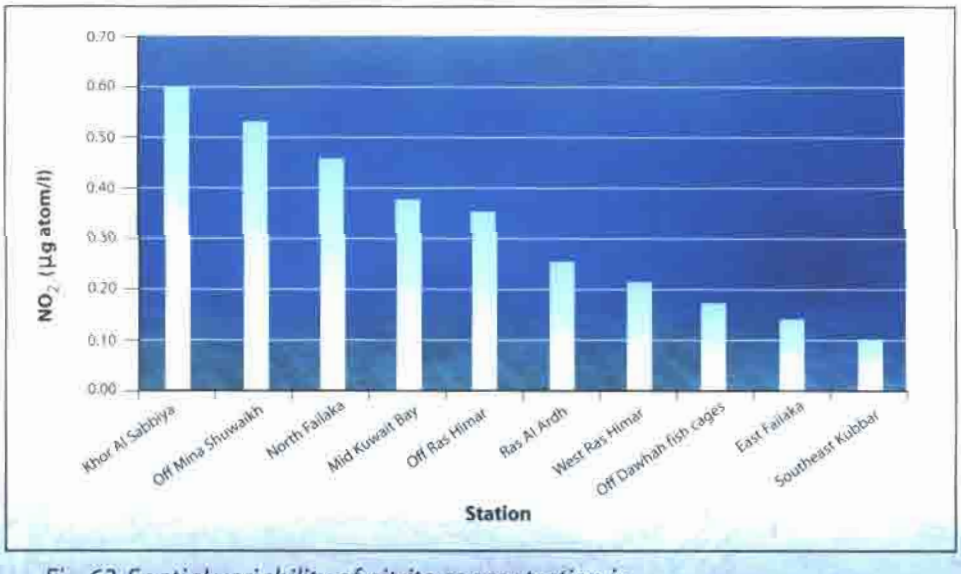


Fig. 63. Spatial variability of nitrite concentration in Kuwait's waters (2000 - 2002).

Nitrates. Nitrate is a plant nutrient and inorganic fertilizer found in abundance in agricultural fertilizers, manure, industrial wastewaters, animal feed lots and in garbage dumps. Mean nitrate concentration in Kuwait's waters is 2.21 µg-at/l, with a range of 0.0 µg-at/l (undetectable concentration) to 27.1 µg-at/l. In general, nitrate concentration in the spring is usually higher than the other periods due to the impact of nutrient-rich fresh water discharge into Kuwait's northern waters. In addition, discharged waters from the Third River into Khor Al-Sabbiya contain high concentrations of nitrates, as detected in August 1998. Northern waters display higher nitrate concentration than Southern offshore waters. Spatial and seasonal distributions of nitrate concentrations for the years 1996, 1998 and 2000-2002 are displayed in Figs. 64-67.

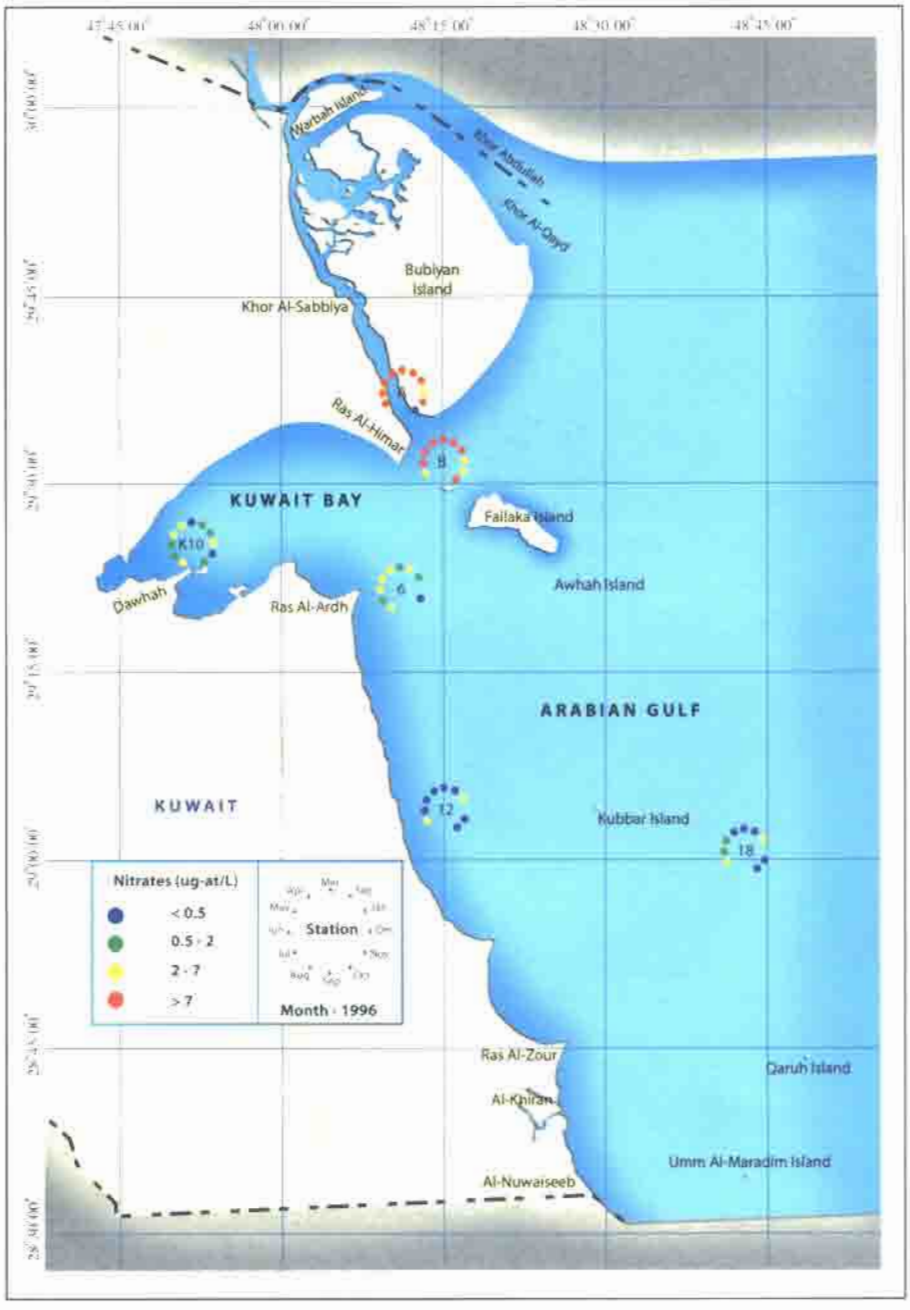


Fig. 64. Spatial and temporal variability of mean nitrate concentration in 1996 in Kuwait's waters.

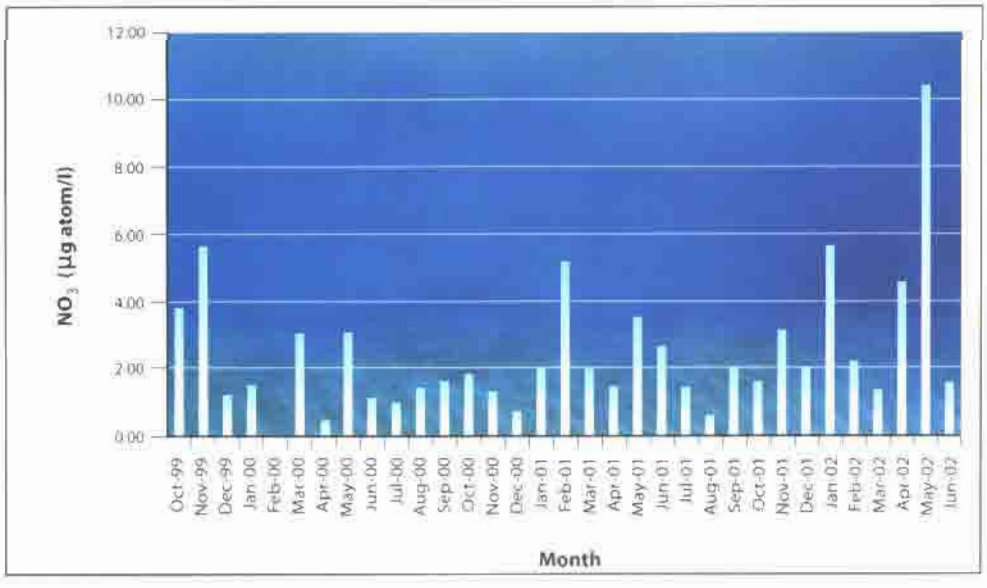


Fig. 65. Temporal variability of nitrate concentration in Kuwait's waters.

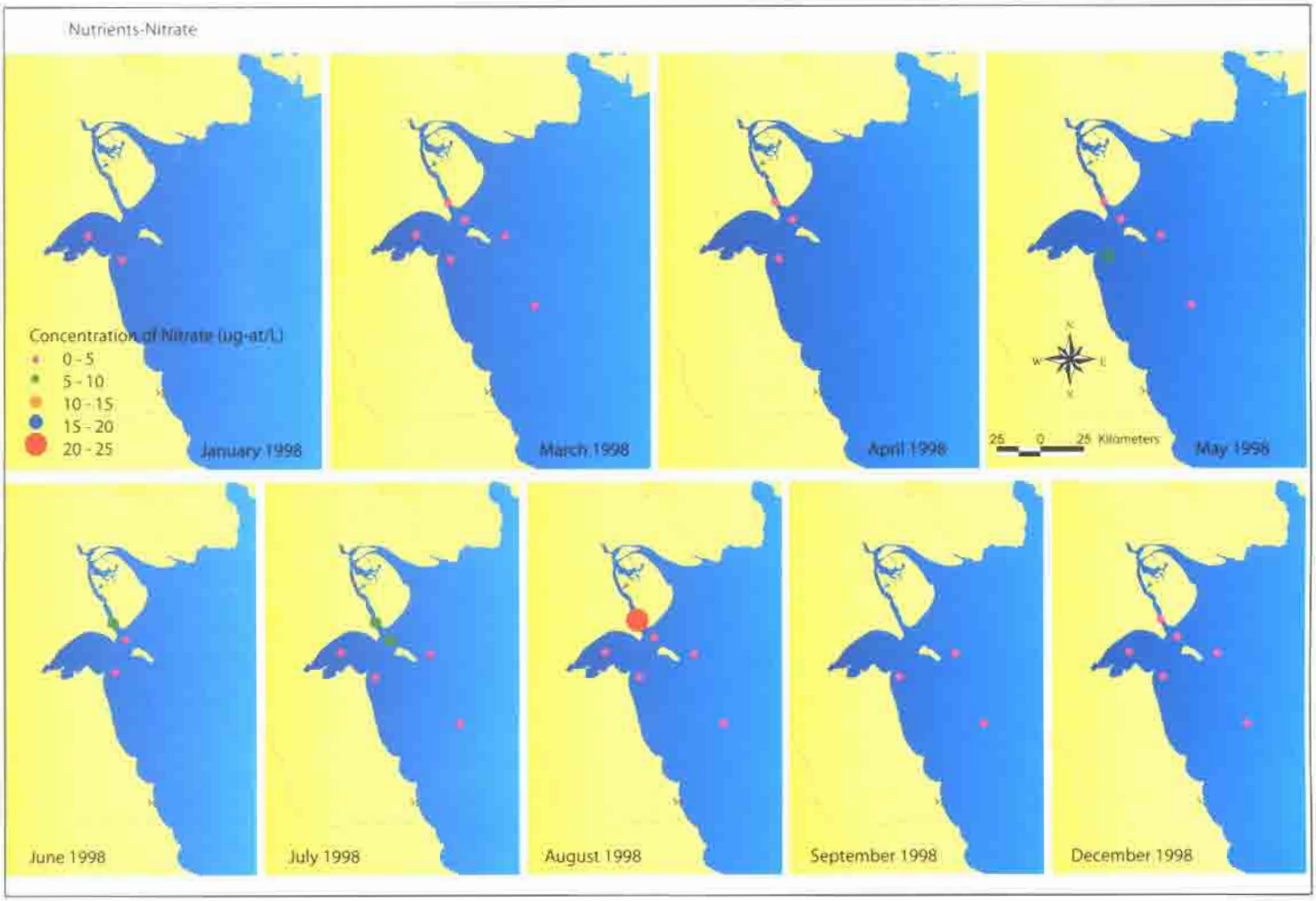


Fig. 66. Spatial and temporal variability of mean nitrate concentration in 1998 in Kuwait's waters.

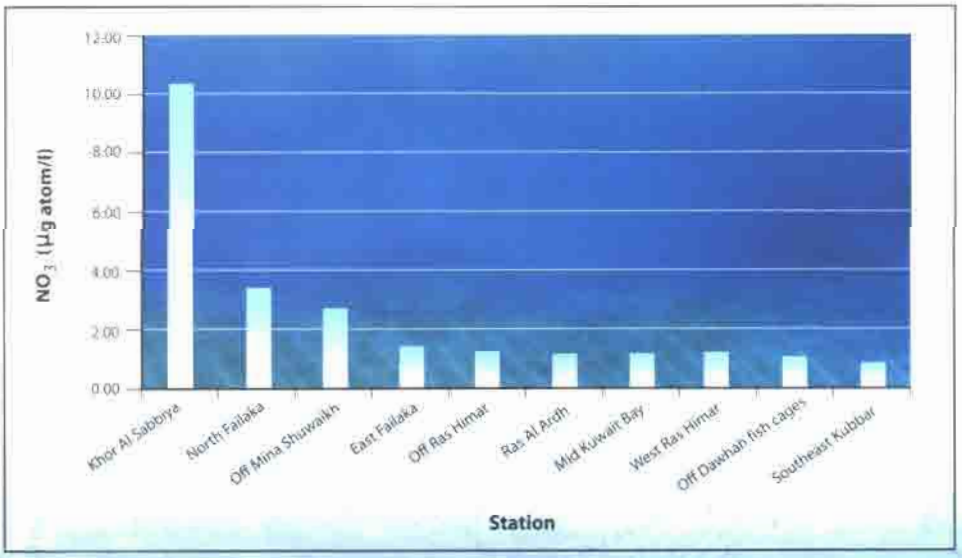


Fig. 67. Spatial variability of nitrate concentration in Kuwait's waters (2000 - 2002).

Phosphates. The mean phosphate concentration is 0.35 µg-at/l, with a range of 0.0 µg-at/l (undetectable concentration) to 5.73 µg-at/l. High phosphate concentrations are usually recorded during the spring period (March-May) in the northern waters. Generally, sporadic pulses occur throughout the year in the Khor Al-Sabbiya area, north of Failaka Island and in Kuwait Bay. Spatial and seasonal distributions of phosphate concentrations for the years 1996, 1998 and 2000-2002 are displayed in Figs. 68-71.

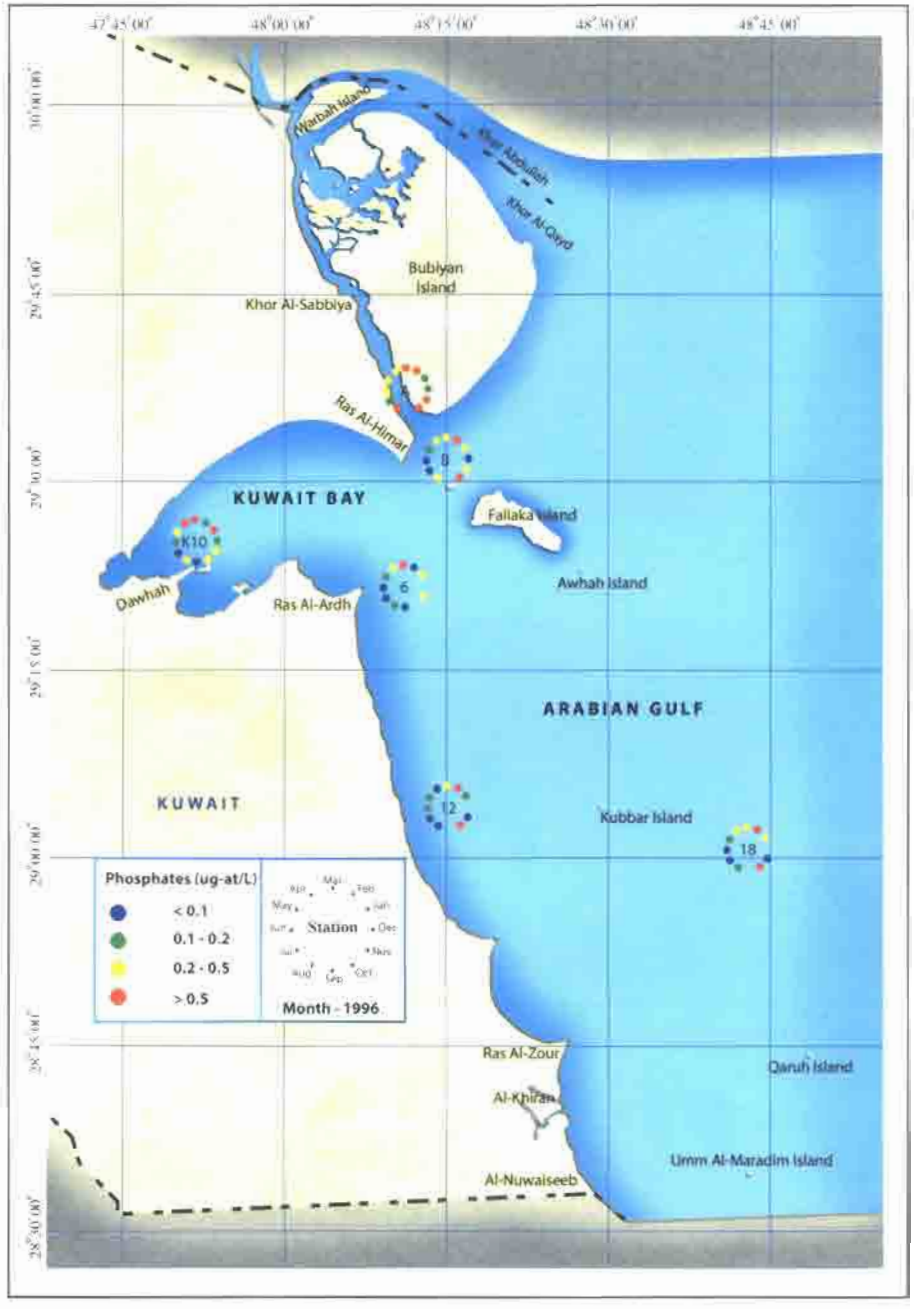


Fig. 68. Spatial and temporal variability of mean phosphate concentration in 1996 in Kuwait's waters.

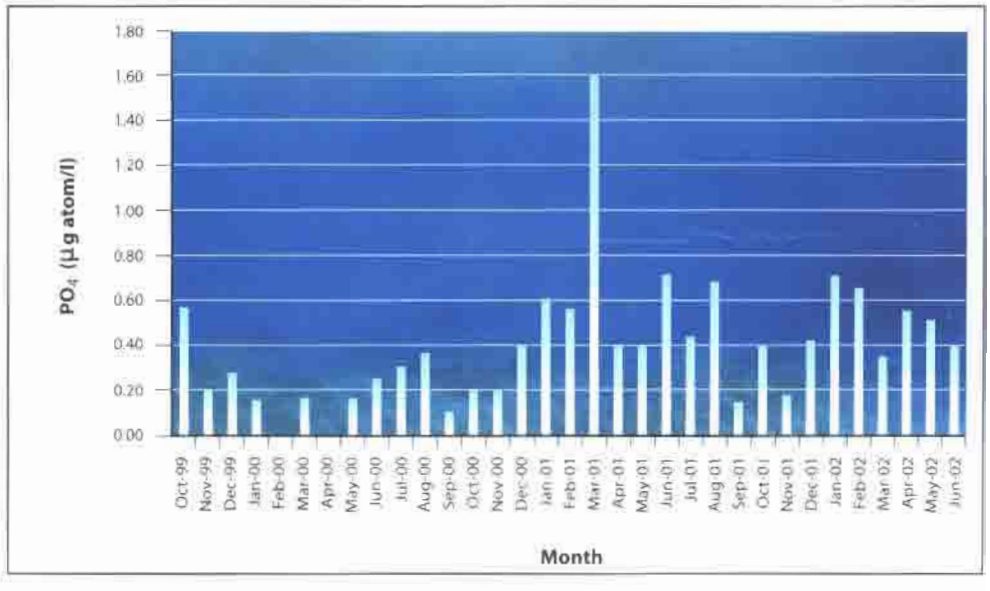


Fig. 69. Temporal variability of phosphate concentration in Kuwait's waters.

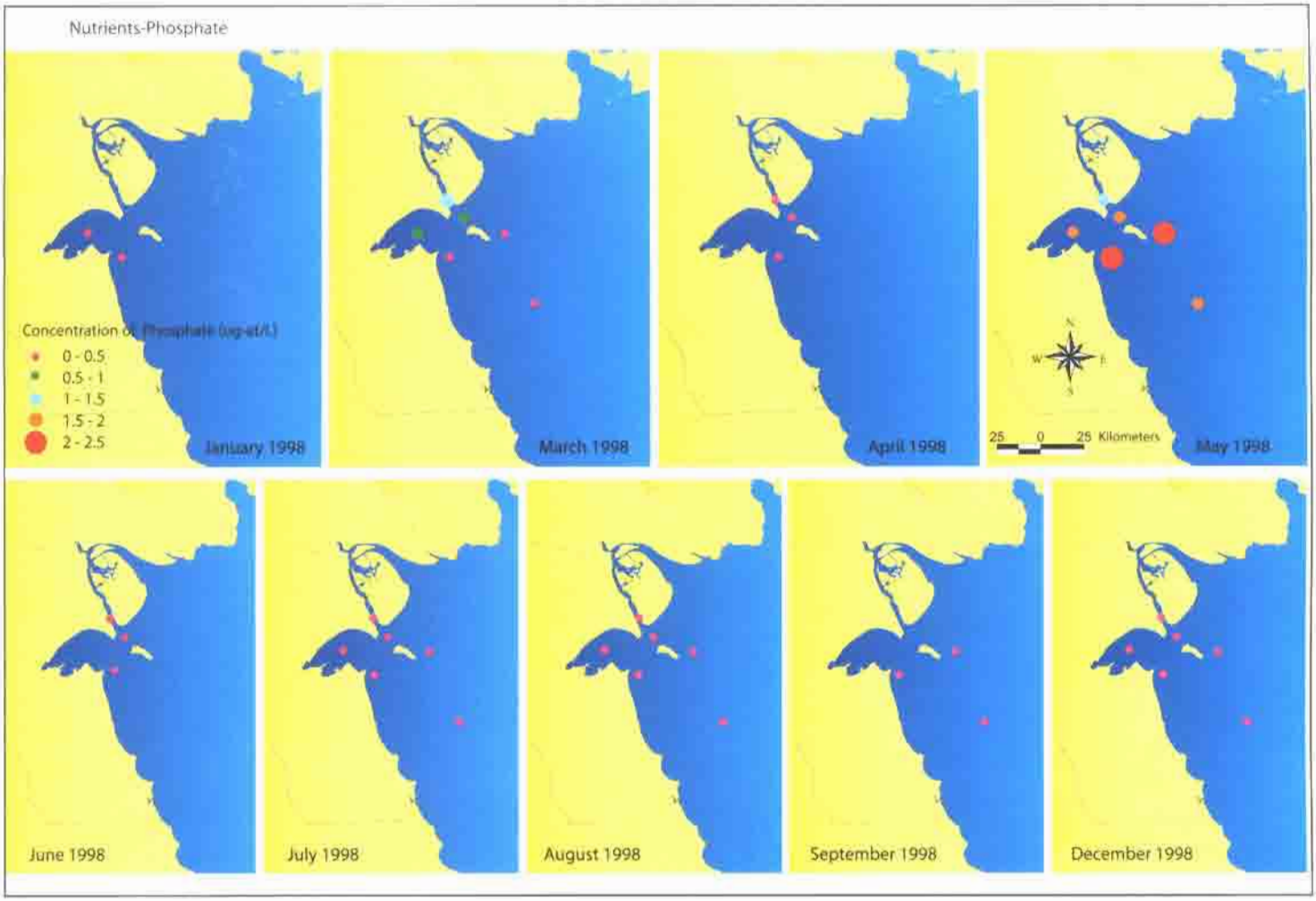


Fig. 70. Spatial and temporal variability of mean phosphate concentration in 1998 in Kuwait's waters.

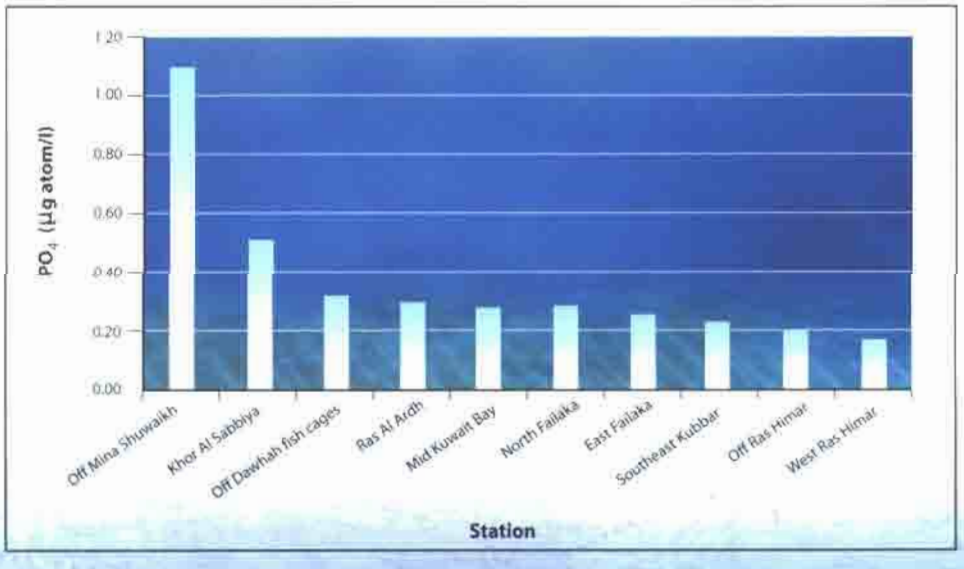


Fig. 71. Spatial variability of phosphate concentration in Kuwait's waters (2000 - 2002).

Silicates. Mean silicate concentration is 12.81 µg-at/l, with a range of 0.0 µg-at/l (undetectable concentration, especially in the offshore southern deep waters) to 51.50 µg-at/l (in northern and inshore waters). In general, silicate concentration exhibits a decreasing trend in a southerly direction. Spatial and seasonal distributions of silicate concentrations for the years 1996, 1998 and 2000-2002 are displayed in Figs. 72-75.

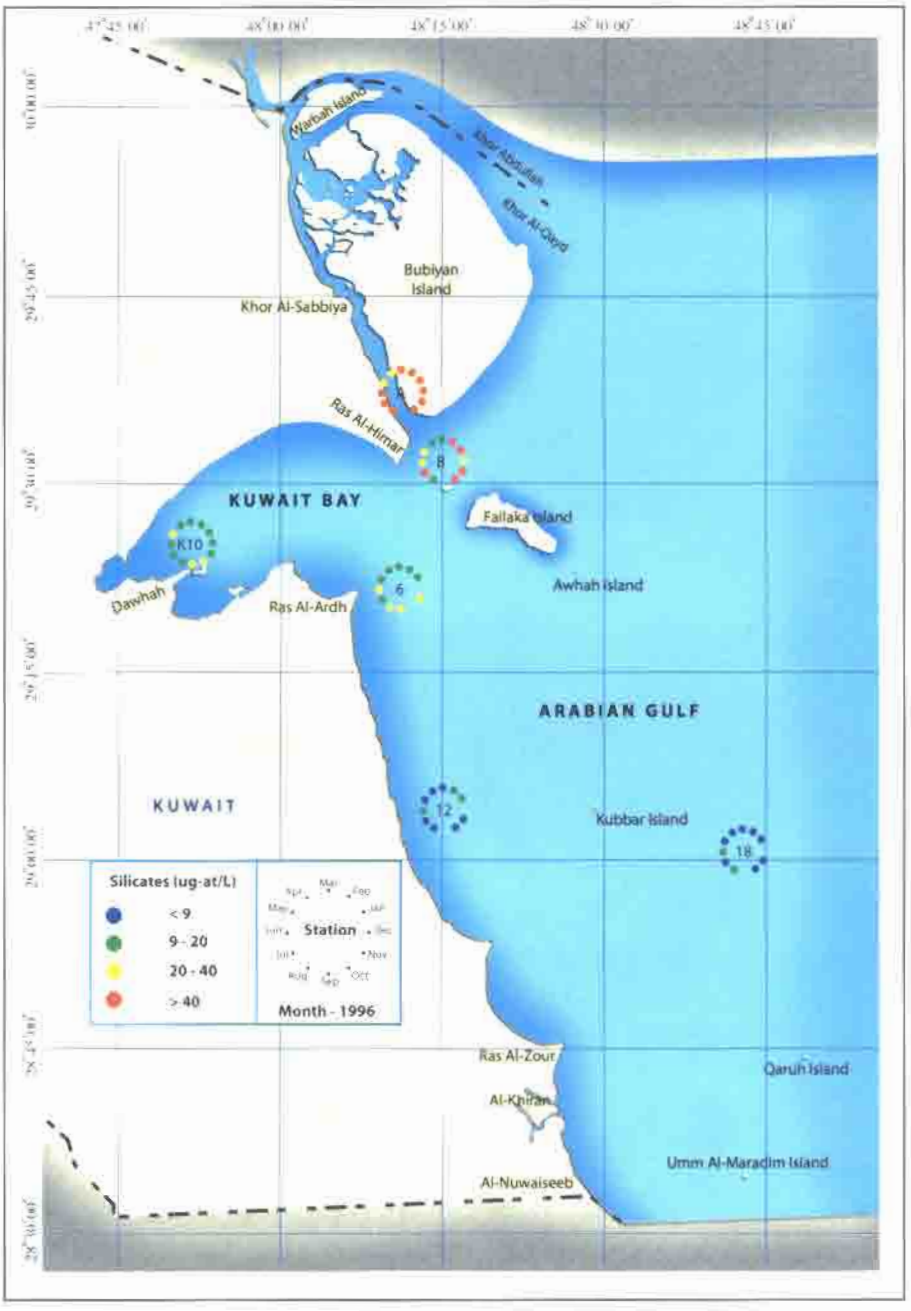


Fig. 72. Spatial and temporal variability of mean silicate concentration in 1996 in Kuwait's waters.

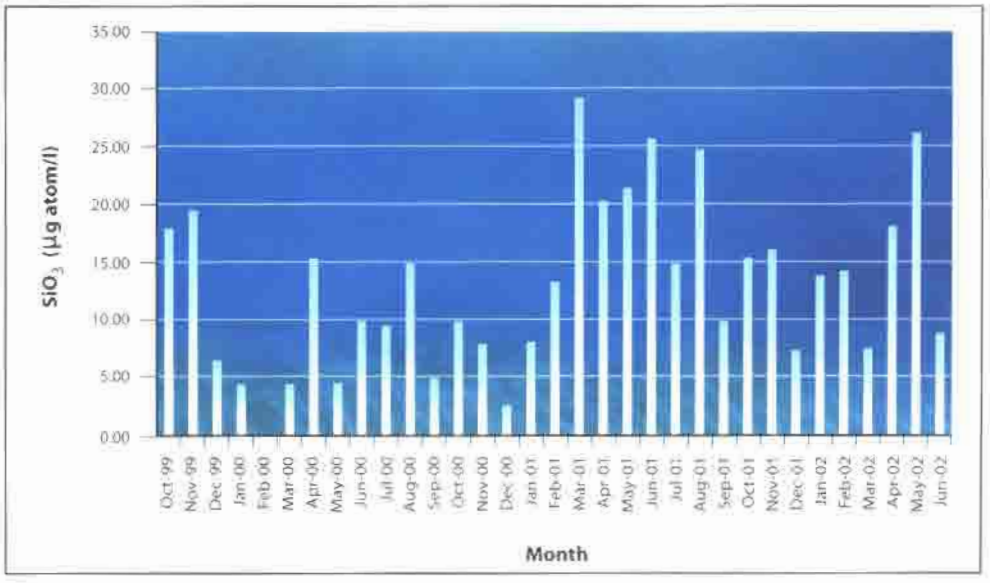


Fig. 73. Temporal variability of silicate concentration in Kuwait's waters.

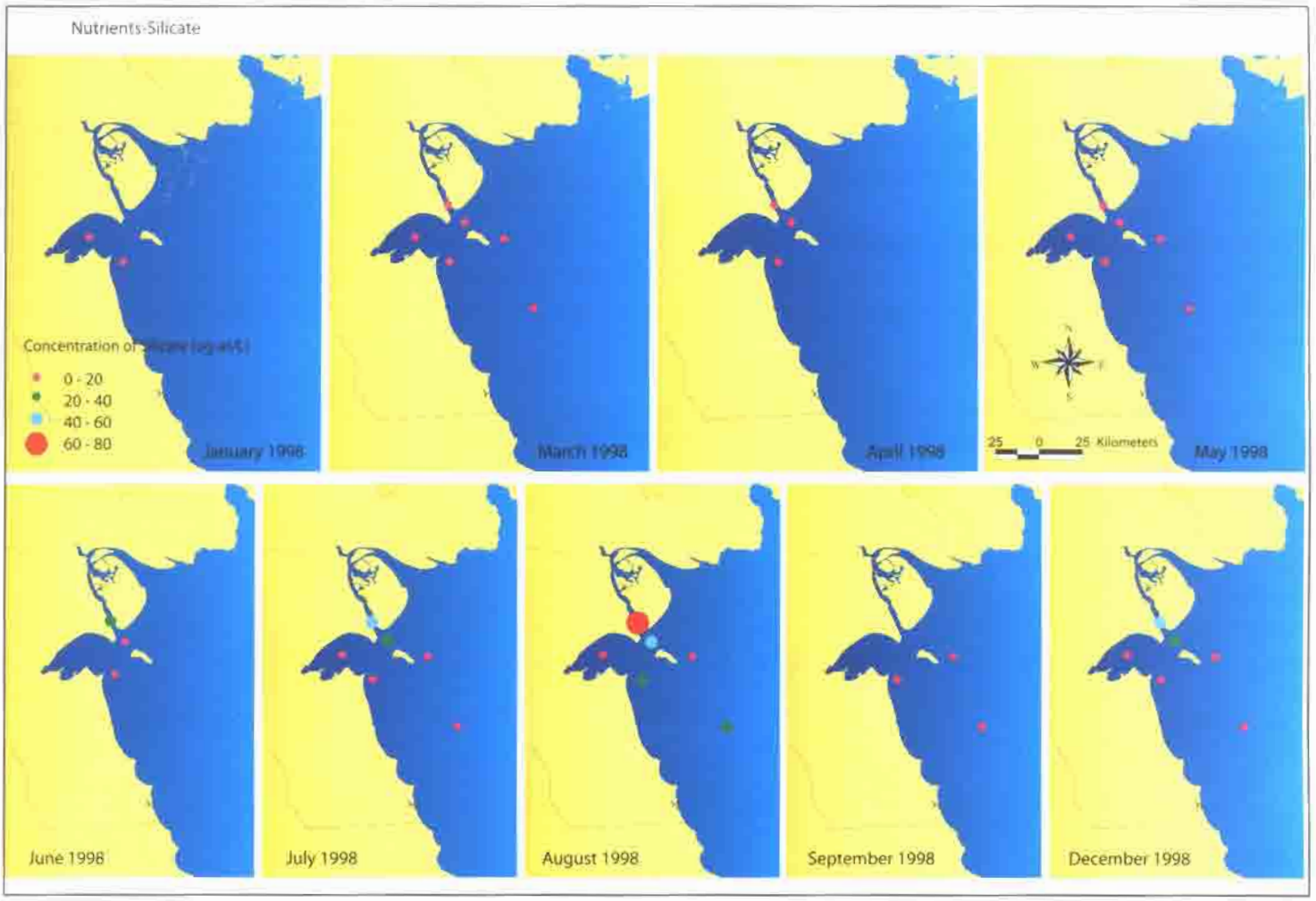


Fig. 74. Spatial and temporal variability of mean silicate concentration in 1998 in Kuwait's waters.

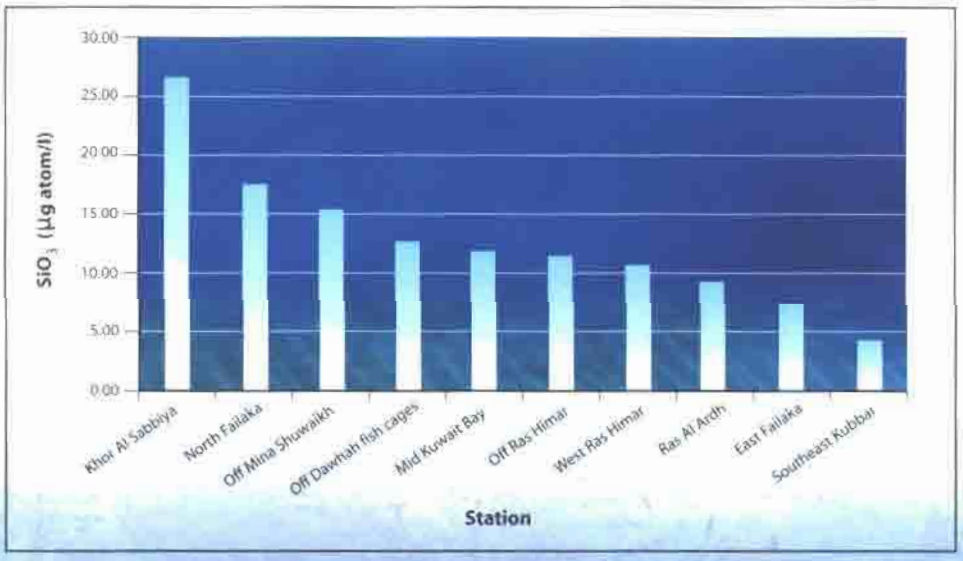


Fig. 75. Spatial variability of silicate concentration in Kuwait's waters (2000 - 2002).

N:P Ratio. The 1996-1997 N:P ratio in Khor Al-Sabbiya and Kuwait Bay, which are in close proximity to major sources of nutrients (e.g., river and sewage discharges, respectively), was 9:1 and well below the Redfield ratio of 16:1, an indication of excess phosphate relative to phytoplankton needs. The N:P ratio in the waters of NW Failaka (23:1) was well above the Redfield ratio, indicating a much more rapid scavenging of phosphate than nitrogen from the water column, and, therefore, phosphate may be the limiting nutrient in these waters.

Biological Oceanography - Plankton

This biological oceanography section describes the temporal and spatial distribution of the plankton community in Kuwait's waters. The missing chlorophyll data for specific dates in the graphs and maps below indicate that no sampling was conducted on these dates.

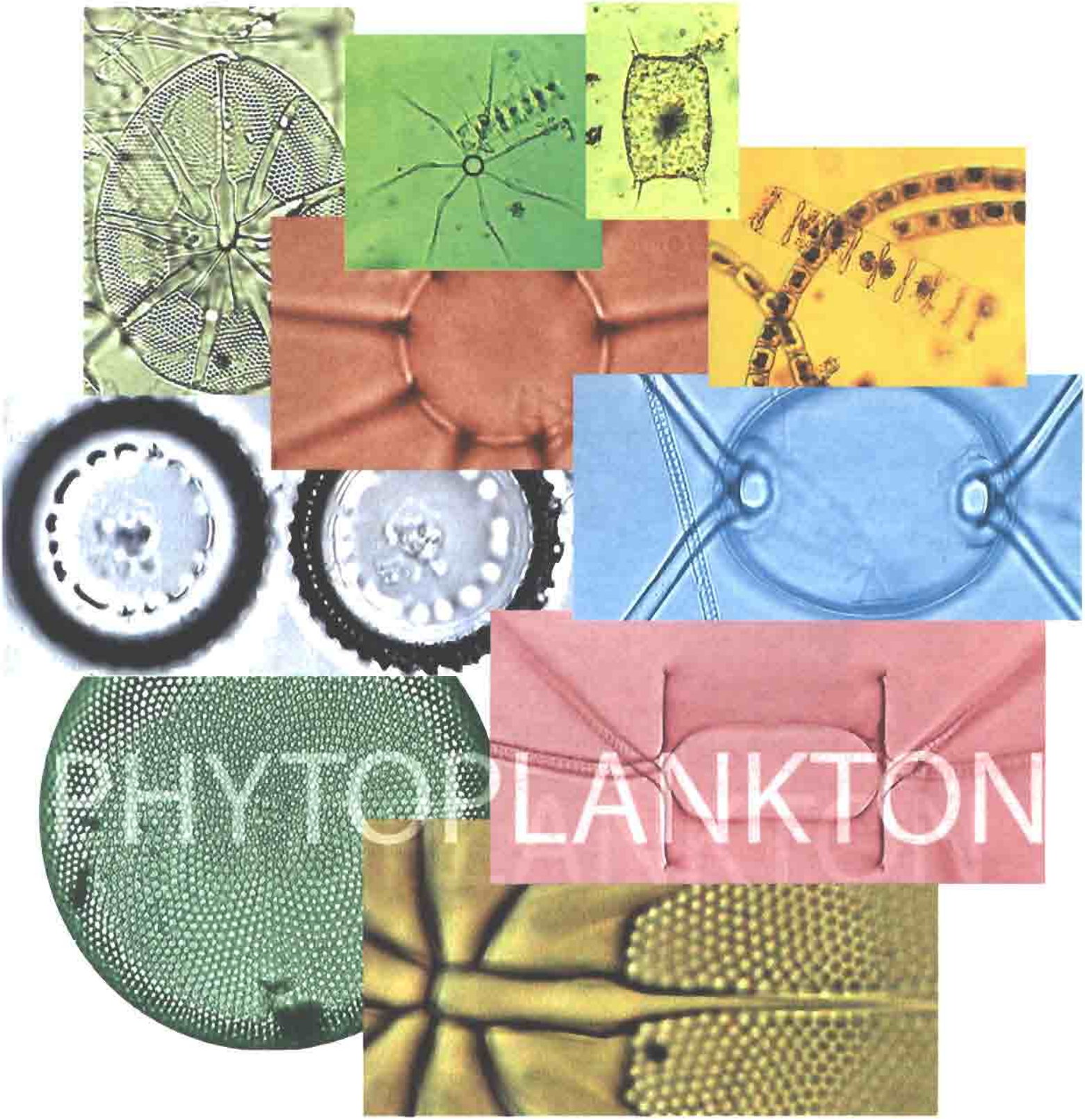
Bacterioplankton. Bacterioplankton abundance is generally high throughout Kuwait's waters. The average abundance of bacteria is about 2 X 10^9 bacteria/l, with a minimum of 0.5 X 10^9 bacteria/l and a maximum of 6.6 X 10^9 bacteria/l. For comparison, bacterial abundance in open ocean surface waters is generally < 1 X 10^9 bacteria/l. Therefore, bacterial abundance in Kuwait's water is remarkably high and fairly constant. There is no obvious trend with either season or distance from shore. There is also no indication of large variations in bacterial abundance with depth, even during the spring, when there is some evidence of water column stratification in salinity in the southern most waters. Kuwait Bay waters do not stand out from the other waters of Kuwait in terms of bacterial abundance, despite the potentially high anthropogenic impact in this area, due to shipping activities, sewage input and other discharge sources. The mean bacterial production rate for Kuwait's waters is generally within the range commonly reported for productive coastal waters, with an assemblage turnover time of 3.5 days. Spatial and seasonal distributions of bacterioplankton for the year 1998 are displayed in Fig. 76.



Fig. 76. Spatial and temporal variability of mean bacterioplankton concentration in 1998 in Kuwait's waters.

Synechococcus, an autotrophic marine bacterium, is abundant throughout Kuwait's waters, with a mean cell density of 0.33 X 10^9 cells/l, a minimum of 0.02 X 10^9 cells/l and a maximum of 1.46 X 10^9 cells/l. *Synechococcus* abundance was found to be the lowest in Kuwait Bay during 1996-1997.

Phytoplankton. Phytoplankton surveys and studies have been conducted for Kuwait's waters and the Arabian Gulf (e.g., Al-Kaisi, 1976; Jamal and Pavlov, 1979; Jacob et al., 1979, 1981; Jacob and Al-Muzaini, 1990; Dorgham et al., 1987; Al-Muzaini and Jacob, 1996; Al-Yamani et al., 1997a, b; Subba Rao and Al-Yamani, 1998; Subba Rao et al., 1999). However, long-term studies on the seasonal and spatial distribution, and the dynamics of the phytoplankton population as well as the effect of the physical forcing in Kuwait's waters need to be studied.



Chlorophyll-*a*. Chlorophyll-*a*, which is an indicator of the amount of plant growth in water or of phytoplankton biomass, has a range of means in Kuwait's waters of 2.0-9.0 µg/l (considered as moderately high), with a minimum value of 0.02 µg/l and maximum of 30 µg/l (excluding values during phytoplankton blooms). Chlorophyll-*a* concentration shows a strong gradient from north to south in Kuwait's waters. Chlorophyll concentrations are high in the northern waters and in Kuwait Bay during winter and early spring, however, there does not appear to be any significant overall seasonal pattern to chlorophyll concentrations in the other waters of Kuwait. Sporadic blooms contribute to high levels of chlorophyll-*a*, reaching up to 1212 µg/l (density of 42 X 10^6 cells/l), as was recorded in July 2002 during a *Nitzschia* sp. bloom in waters off Khor Al-Sabbiya. Spatial and temporal distributions of chlorophyll-*a* for the years 1996, 1998 and 2000-2002 are displayed in Figs. 77-80.

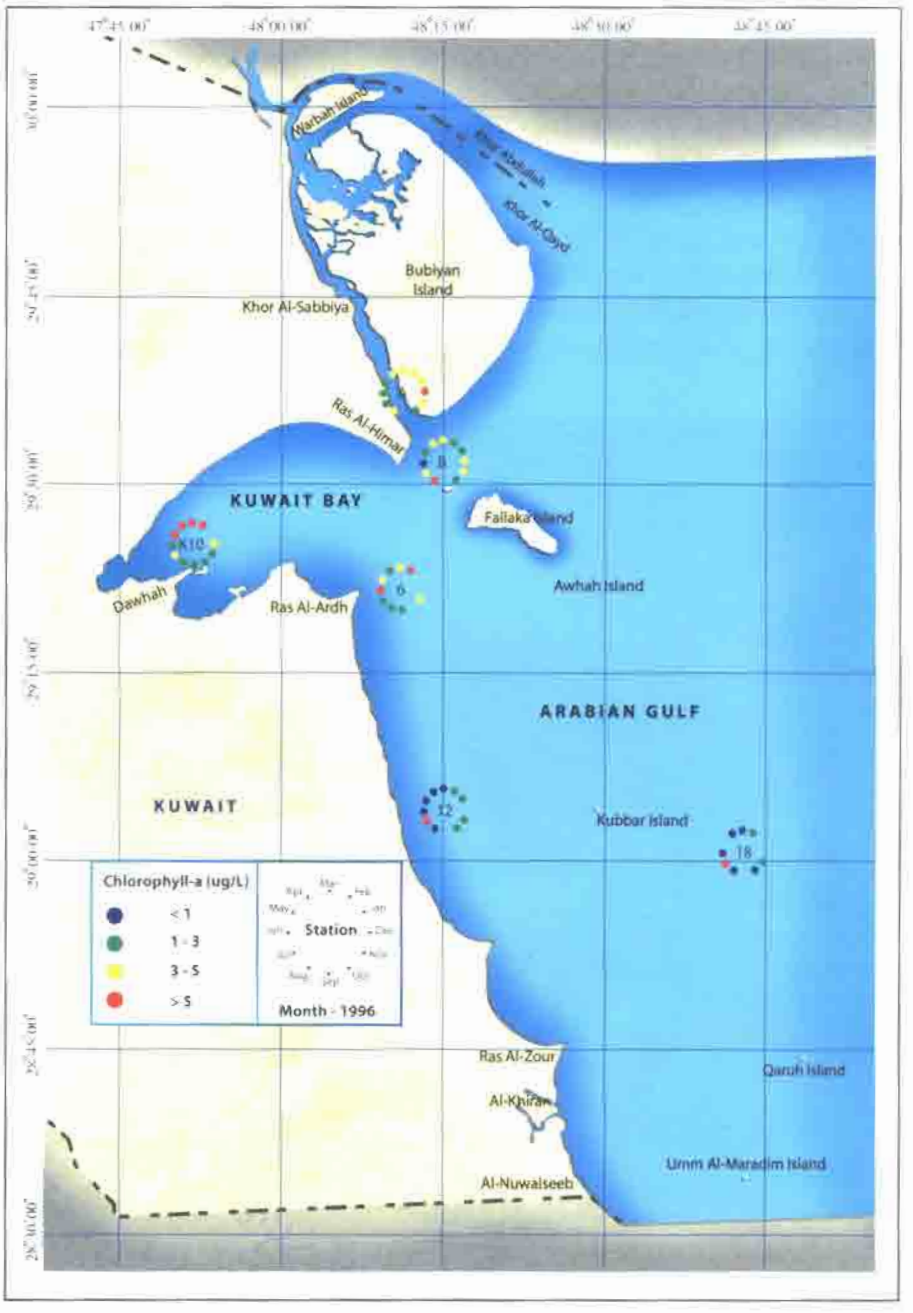


*Fig. 77. Spatial and temporal variability of mean chlorophyll-**a** concentration in 1996 in Kuwait's waters.*

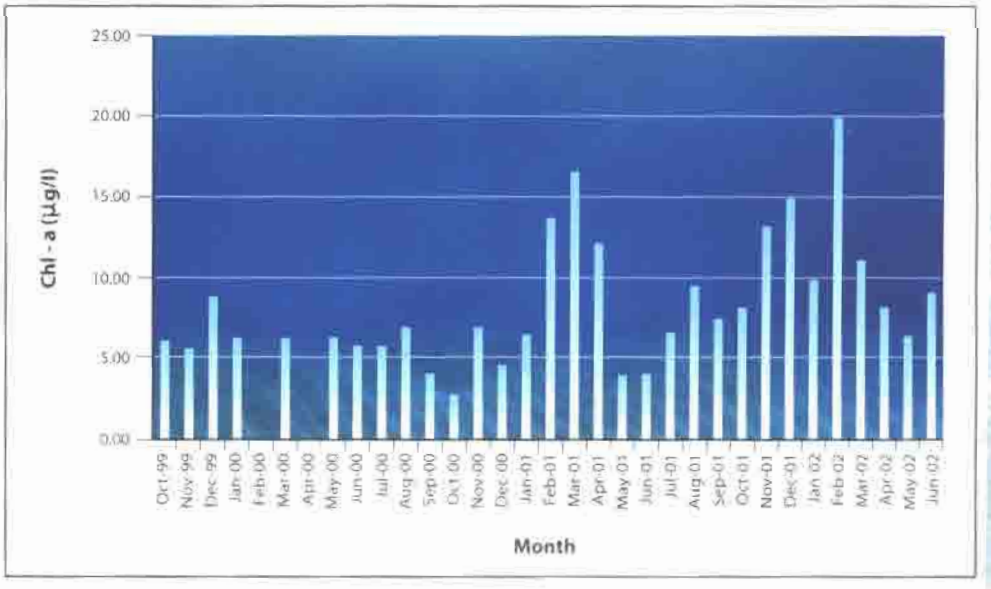


*Fig. 78. Temporal variability of mean chlorophyll-**a** concentration in Kuwait's waters.*

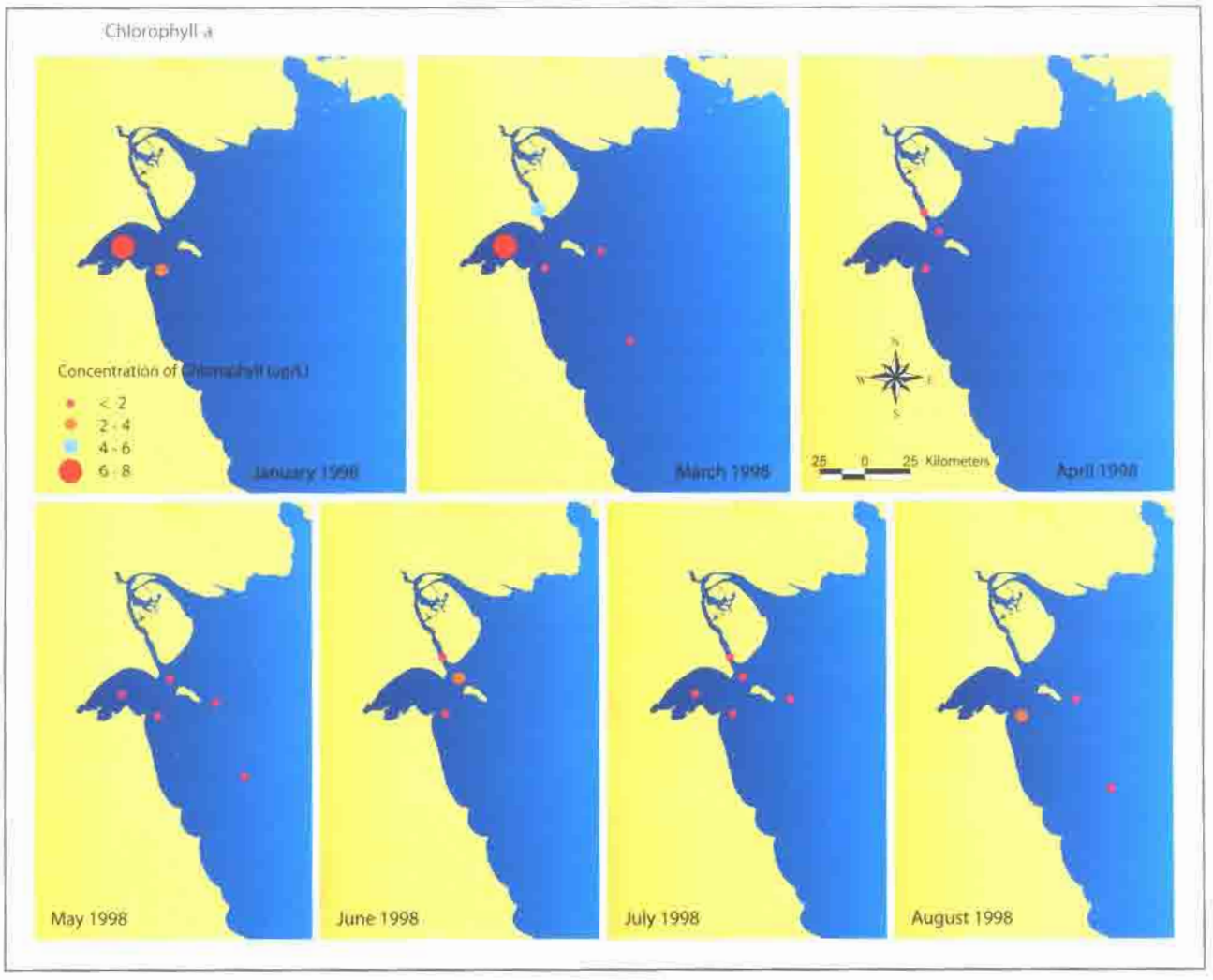


*Fig. 79. Spatial and temporal variability of mean chlorophyll-**a** concentration in 1998 in Kuwait's waters.*

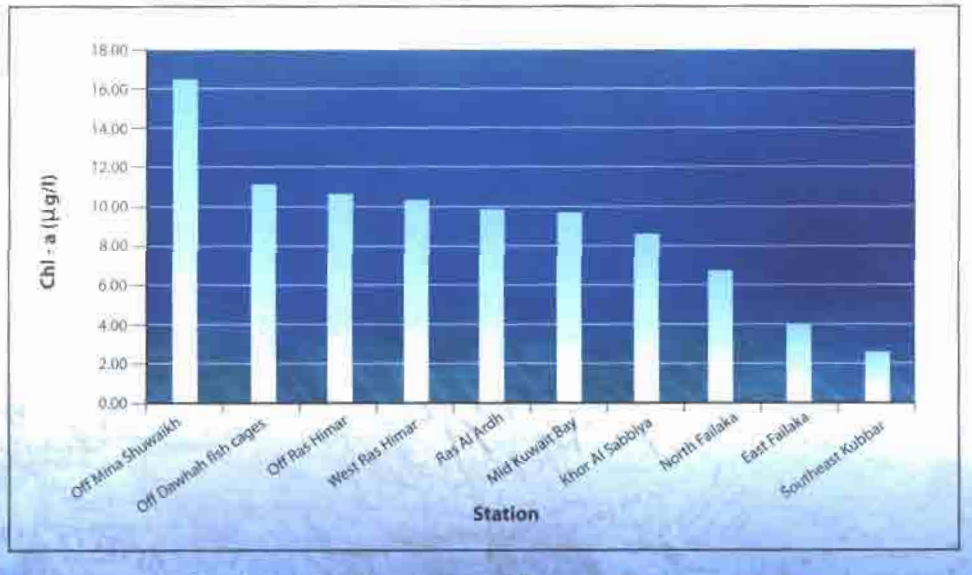


*Fig. 80. Spatial variability of mean chlorophyll-**a** concentration in Kuwait's waters (2000 - 2002).*

Primary Productivity. Primary productivity estimates are lacking for the Arabian Gulf, except for three rough estimates given by Huq et al. (1978), Jacob et al. (1979) and FAO (1982). According to the *Atlas of the Living Resources of the Sea* (FAO, 1982), average primary productivity of phytoplankton in the Gulf is > 500 mgC/m^2/d, which is considered as a medium to high productivity value according to the 1986 Nixon index. Al-Yamani et al. (1997b) reported primary productivity estimates for Kuwait's waters, with a mean productivity value of 152.9 µgC/l/d (range of 11 to 610 µg C/l/d), which indicates moderate productivity similar to other coastal waters in the world. Primary production seems to be affected by turbidity levels and nutrient enrichment, partly due to the fresh water inputs from the north (Shatt Al-Arab and the Third River) and anthropogenic input in Kuwait Bay.

Assimilation Number. Potential photosynthetic efficiency or assimilation number for Kuwait's waters is high and ranges from 15 to <25 µg C (µg chl-*a*)$^{-1}$ h^{-1} at most stations with lower values [<10 µg C (µg chl-*a*)$^{-1}$ h^{-1}] observed in the highly stressed Kuwait Bay waters.

Phytoplankton Community Composition. Phytoplankton species composition in Kuwait's waters has a heterogenous spatial distribution, with different size structures in the different localities. In general, small phytoplankton species are predominant in the more turbid and dynamic northern waters (Khor Al-Sabbiya and northern Failaka), whereas there is a



Fig. 81. Temporal and spatial distribution of mean abundance of total phytoplankton in Kuwait's waters.

predominance of large species that occur in Kuwait Bay and in the southern Kuwaiti waters. This spatial heterogeneity in phytoplankton community structure may have an effect on the distribution of the herbivorous zooplankton community. Littoral diatom flora are quite rich and diverse (Hendy, 1970).

The maximum number of phytoplankton taxa recorded in the Arabian Gulf area is about 223, which consists of 134 species of diatoms, 86 species of dinoflagellates, two species of blue-green algae (Cyanobacteria), and one species of silicoflagellate (Jacob and Al-Muzaini, 1990). Species diversity is usually lower in the northern Gulf and increases toward the southern Gulf waters (Subba Rao and Al-Yamani, 1998). The number of diatom taxa recorded in the waters of Kuwait, Saudi Arabia and Qatar were nearly similar, whereas, for dinoflagellates, significant regional variations were observed.

Some of the common diatom genera in Kuwait's waters are: *Chaetoceros, Nitzschia, Coscinodiscus, Rhizosolenia, Thalassiothrix,* and *Thalassiosira,* while *Ceratium* is a common dinoflagellate genus. Mean phytoplankton density in Kuwait's waters ranges from 3098 cells/liter to 1,821,655 cells/liter. However, during monospecific blooms, single species density can exceed one million/liter. For example, during a monospecific bloom of *Nitzschia* off Khor Al-Sabbiya in July 2002, the density was 42 X 10^6 cells/liter. In general, higher densities are found in Kuwait Bay and off Ras Al-Ardh, and lower values are usually found in the offshore southern waters and in the turbid waters of Khor Al-Sabbiya and northern Failaka. Spatial and temporal distribution of total phytoplankton and of selected phytoplankton groups for the year 1996/1997 are displayed in Figs. 81-87.



Fig. 82. Temporal and spatial distribution of mean abundance of total ***Nitzschia*** *spp. in Kuwait's waters.*



Fig. 83. Temporal and spatial distribution of mean abundance of total ***Coscinodiscus*** *spp. in Kuwait's waters.*

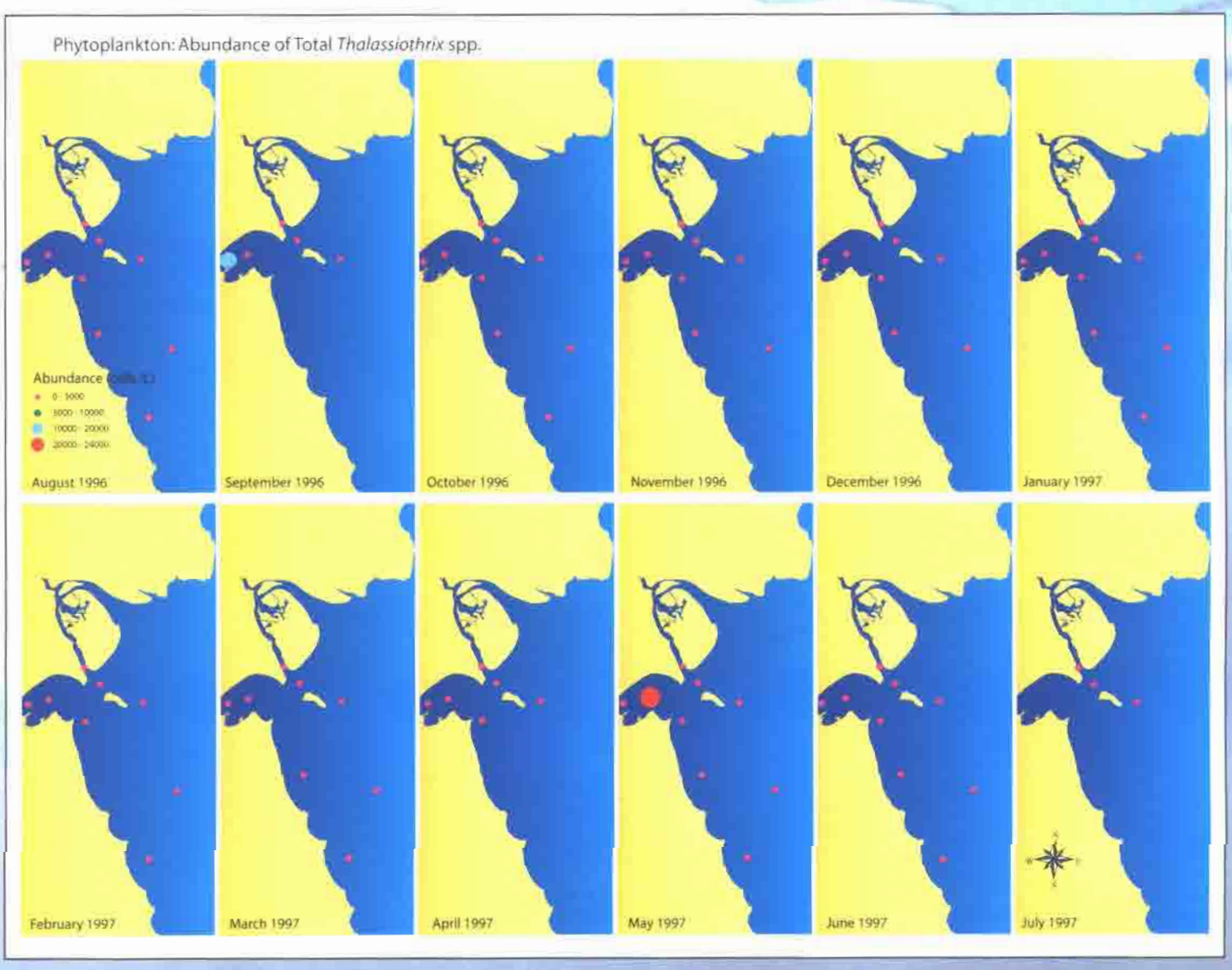


Fig. 84. Temporal and spatial distribution of mean abundance of total ***Thalassiothrix*** *spp. in Kuwait's waters.*

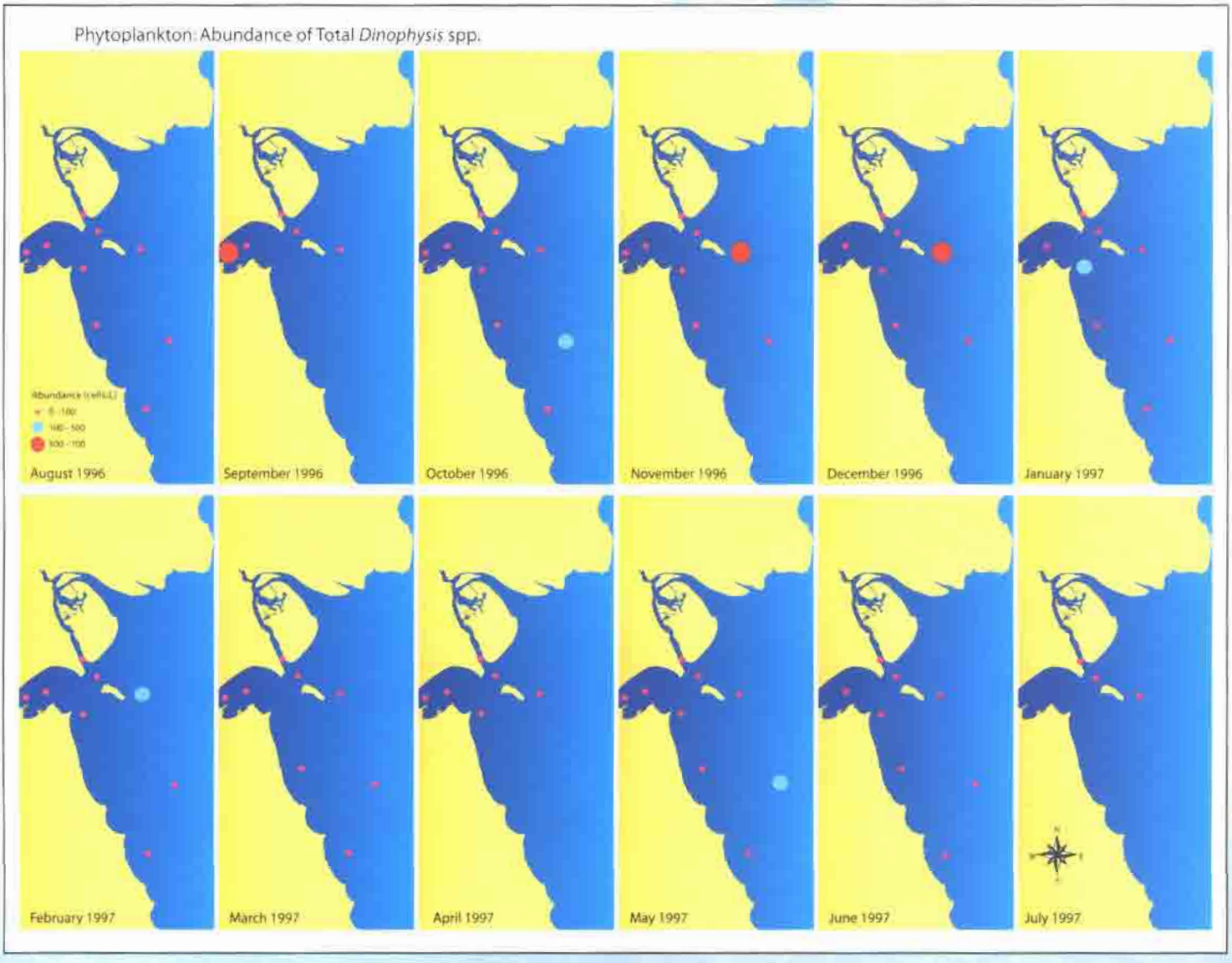


Fig. 85. Temporal and spatial distribution of mean abundance of total ***Dinophysis*** *spp. in Kuwait's waters.*

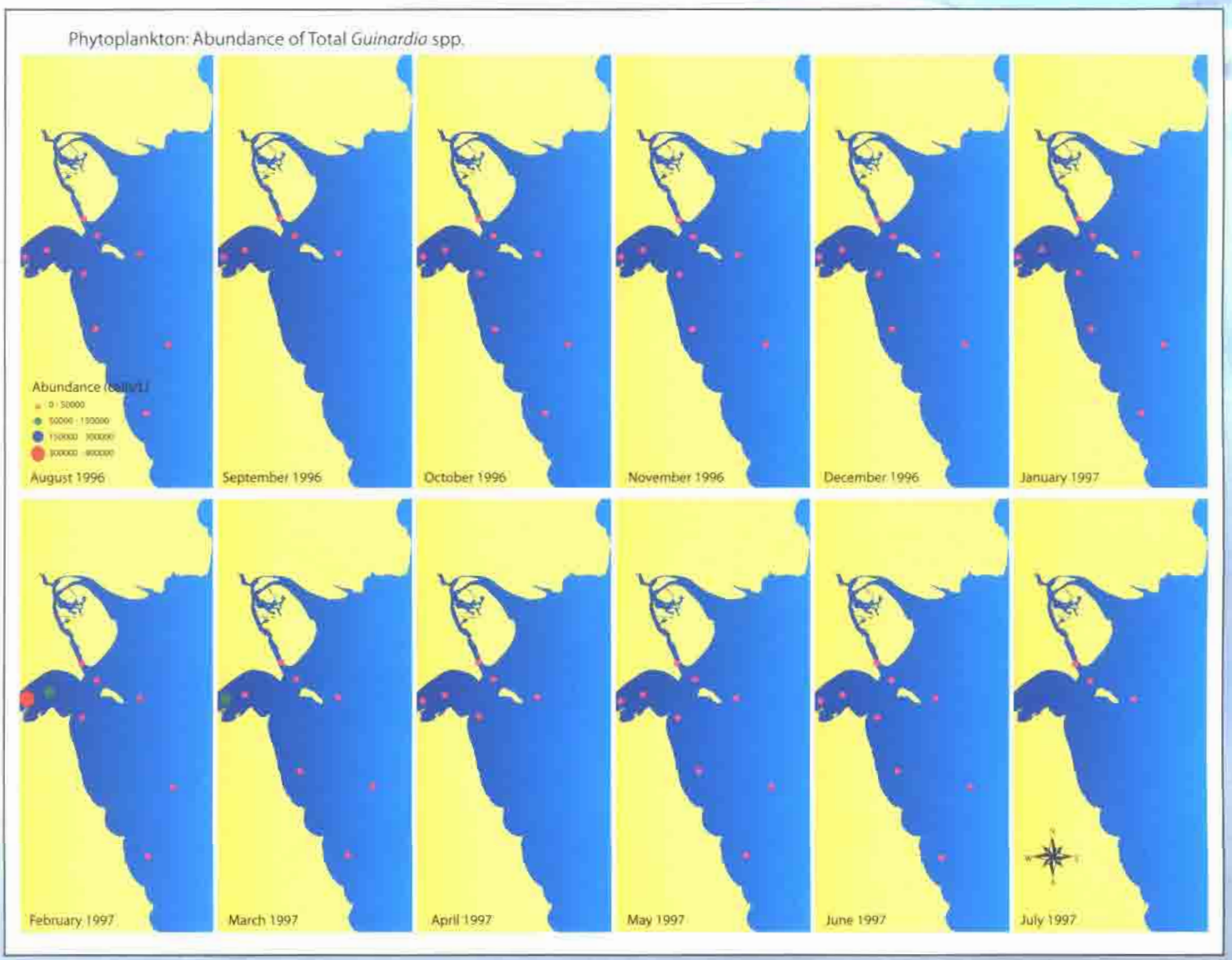


Fig. 86. Temporal and spatial distribution of mean abundance of total ***Guinardia*** *spp. in Kuwait's waters.*



Fig. 8 7. Temporal and spatial distribution of mean abundance of total ***Biddulphia (Odontella)*** *spp. in Kuwait's waters.*

The table below lists the prevalent phytoplankton species (biodiversity) in Kuwait's waters.

Phylum	Class	Sub-Class	Order	Family	Genus and Species
Bacillariophyta (Diatoms)	Coscinodiscophyceae (centric diatoms)		Thalassiosirales	Thalassiosiraceae	*Thalassiosira rotula*
					Thalassiosira subtilis
					Thalassiosira spp.
					Coscinosira sp.
					Skeletonema sp.
					Schroederella sp.
				Stephanodiscaceae	*Cyclotella menghiniana*
					Cyclotella striata
				Lauderiaceae	*Lauderia annulata*
					Lauderia borealis
			Melosirales	Melosiraceae	*Melosira Monliliformis*
			Paraliales	Paraliaceae	*Paralia sulcata*
			Coscinodiscales	Coscinodiscaceae	*Coscinodiscus grani*
					Coscinodiscus cf. *oculus-iridis*
					Coscinodiscus cf. *stellaris*
					Coscinodiscus spp.
				Hemidiscaceae	*Actinocyclus rotula*
					Hemidiscus cuneiformis
					Hemidiscus spp.
					cf. *Roperia* sp.
			Asterolamprales	Asterolampraceae	*Asteromphalus heptactis*
		Biddulphiophycidae	Triceratiales	Triceratiaceae	*Triceratium favus*
			Biddulphiales	Biddulphiaceae	*Biddulphia* mobiliensis*
					Biddulphia sinensis*
					Biddulphia regia*
					Biddulphia longicruris*
					Biddulphia syn. Odontella*
					Biddulphia pulchella
					Biddulphia spp.
					Trigonium shadboltianum
				Fragilariaceae	*Asterionellopsis glacialis*
					Striatella sp.
			Hemiaulales	Hemiaulaceae	*Hemiaulus sinensis*
					Hemiaulus indicus
					Hemiaulus membranaceus
					Hemiaulus sp.
					Cerataulina bergonii
					Cerataulina pelagica
					Cerataulina cf. *dentata*
					Cerataulina sp.
					Eucampia groenlandica
					Eucampia zoodiacus
				Bellerocheaceae	*Bellerochea horologicalis*
					Bellerochea sp.
				Lithodesmiaceae	*Ditylum brightwellii*
				Streptothecaceae	*Streptotheca thamesis*
		Rhizosoleniophycida	Rhizosoleniales	Rhizosoleniaceae	*Rhizosolenia alata*
					Rhizosolenia bergonii
					Rhizosolenia calcar-avis
					Rhizosolenia cochlea
					Rhizosolenia crassispina
					Rhizosolenia hebetata

Phylum	Class	Sub-Class	Order	Family	Genus and Species
					Rhizosolenia imbricata
					Rhizosolenia robusta
					Rhizosolenia setigera
					Rhizosolenia shrubsolei
					Rhizosolenia stolterfothii
					Rhizosolenia styliformis
					Rhizosolenia cf. *decipiens*
					Rhizosolenia sp.
					Guinardia flaccida
					Guinardia sp.
					Dactyliosolen spp.
		Chaetocerotophycidae	Chaetocerotales	Chaetocerotaceae	*Chaetoceros affinis*
					Chaetoceros atlanticus
					Chaetoceros coarctatus
					Chaetoceros convolutus
					Chaetoceros costatus
					Chaetoceros curvisetum
					Chaetoceros decipiens
					Chaetoceros denticulatum
					Chaetoceros didymus
					Chaetoceros diversus
					Chaetoceros laciniosus
					Chaetoceros leavis
					Chaetoceros lorenzianus
					Chaetoceros peruvianus
					Chaetoceros pseudocurvisetum
					Chaetoceros teres
					Chaetoceros tortissimum
					Chaetoceros cf. *coarctatus*
					Chaetoceros spp.
					Bacteriastrum delicatulum
					Bacteriastrum varians
					Bacteriastrum hyalinum
					Bacteriastrum cf. *delicatulum*
					Bacteriastrum cf. *varians*
					Bacteriastrum spp.
			Leptocylindrales	Leptocylindraceae	*Leptocylindrus danicus*
					Leptocylindrus minimus
					Corethron criophilum
	Fragilariophyceae (Araphid, pennate diatoms)	Fragilariophycidae	Fragilariales	Fragilariaceae	*Opephora marina*
					Opephora sp.
			Thalassionematales	Thalassionemataceae	*Thalassionema nitzschioides*
					Thalassiothrix frauenfeldii
					Thalassiothrix longissima
			Rhabdonematales	Rhabdonemataceae	*Rhabdonema* sp.
			Striatellales	Striatellaceae	*Grammatophora marina*
	Bacillariophyceae (Raphid, pennate diatoms)	Bacillariophycidae	Lyrellales	Lyrellaceae	*Lyrella lyra var. dilatata*
					Lyrella sp.
			Mastogloiales	Mastogloiaceae	*Mastogloia apiculata*
					Mastogloia erythraea
					Mastogloia inaequalis
					Mastogloia Mac-Donaldii
					Mastogloia sp.
			Cymbellales	Gomphonemataceae	*Gomphonema* sp.

Phylum	Class	Sub-Class	Order	Family	Genus and Species
			Achnanthales	Cocconeidaceae	*Cocconeis placentula*
			Naviculales	Pinnulariaceae	*Caloneis* cf. *westii*
				Diploneidaceae	*Diploneis chersonensis*
					Diploneis smithii
					Diploneis suborbicularis
					Diploneis weissflogi
					Diploneis sp.
				Naviculaceae	*Navicula directa v. remota*
					Navicula yarrensis
					Navicula cf. *concellata*
					Navicula spp.
					Oestrupia sp.
					Trachyneis sp.
					Climaconeis sp.
					Haslea spp.
				Pleurosigmataceae	*Pleurosigma diverse-striatum*
					Pleurosigma formosum
					Pleurosigma spp.
					Gyrosigma diminutum
				Plagiotropidaceae	*Plagiotropis lepidoptera*
				Stauroneidaceae	*Stauroneis membranacea*
			Thalassiophysales	Catenulaceae	*Amphora granulata var. biggibbosa*
					Amphora obtusa
					Amphora robusta
					Amphora securicula
					Amphora cf. *quadrata*
					Amphora cf. *ostrearia*
					Amphora spp.
			Bacillariales	Bacillariaceae	*Bacillaria paradoxa*
					Pseudonitzschia pungens
					Pseudonitzschia spp.
					Nitzschia angularis
					Nitzschia closterium
					Nitzschia constricta
					Nitzschia longa
					Nitzschia longissima
					Nitzschia lorenziana
					Nitzschia punctata v. coarctata
					Nitzschia seriata
					Nitzschia socialis
					Nitzschia socialis v. massiliensis
					Nitzschia panduriformis
					Nitzschia cf. *fluminensis*
					Nitzschia cf. *Insignis*
					Nitzschia cf. *punctata*
					Nitzschia cf. *socialis*
					Nitzschia spp.
			Surirellales	Entomoneidaceae	*Entomoneis (Amphiprora) poludosa*
					Entomoneis sulcata
					Amphiprora sp.
				Auriculaceae	*Auricula* sp.
				Surirellaceae	*Surirella fastuosa*
					Surirella fastuos var.
					Surirella spp.
					Plagiodiscus nervatus

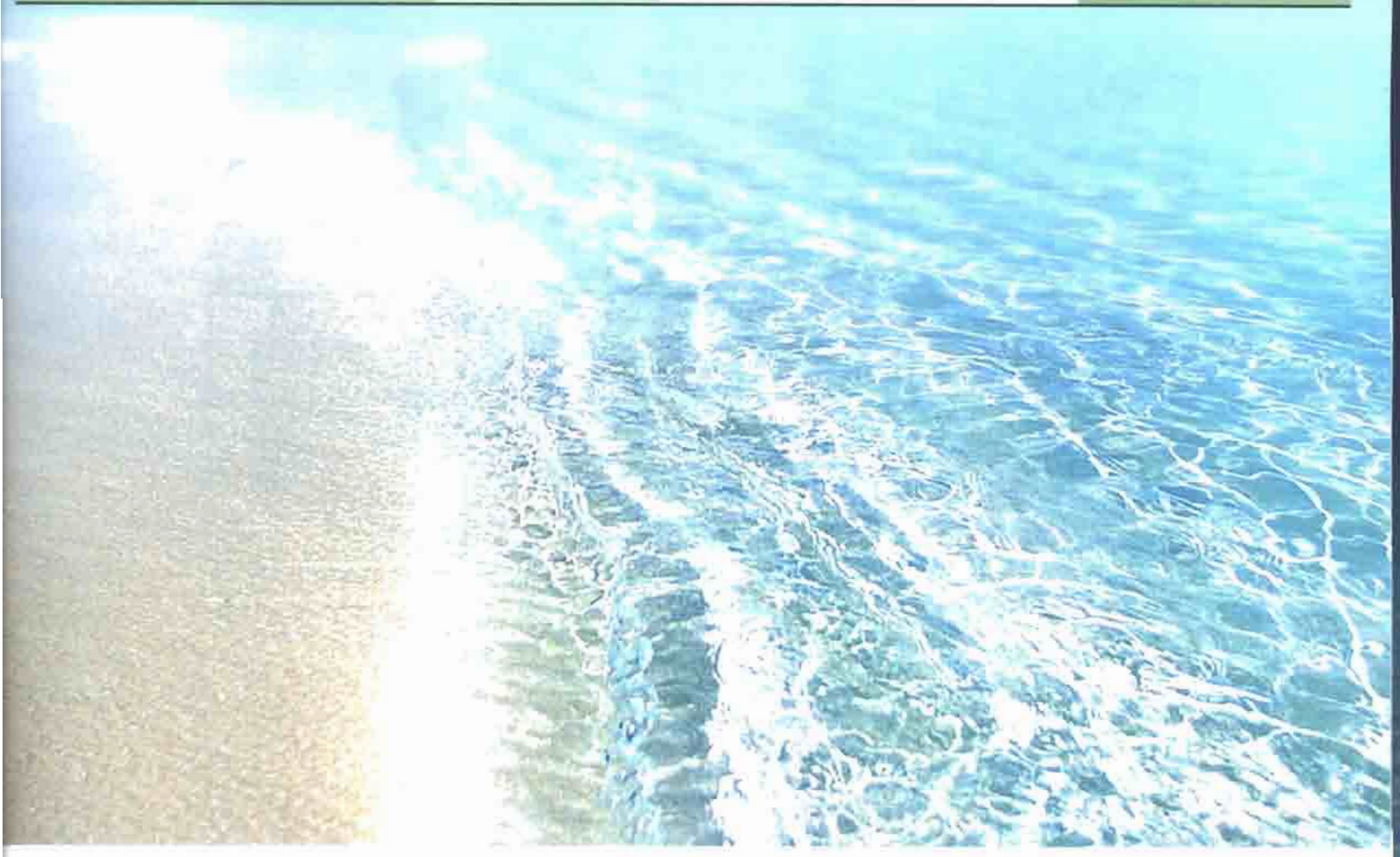
Phylum	Class	Sub-Class	Order	Family	Genus and Species
Pyrrophyta (or Dinophyta)-Dinoflagellates	Dinophyceae		Prorocentrales	Prorocentraceae	*Prorocentrum gracile*
					Prorocentrum micans
					Prorocentrum mexicanum
					Prorocentrum redfieldi
					Prorocentrum spp.
					Exuviaella cf. *E. Baltica*
			Dinophysiales	Dinophysiaceae	*Dinophysis acuminata*
					Dinophysis caudata
					Dinophysis norvegica
					Dinophysis tripos var.
					Dinophysis cf. *rotundata*
					Ornithocercus magnificus
					Ornithocercus thumii
					Ornithocercus sp.
					Parahistioneis sp.
					Phalacroma sp.
			Gymnodiniales	Gymnodiniaceae	*Gymnodinium breve* (*Karenia breve*)
					Gymnodinium impudicum
					Karenia selliformе
					Gymnodiniums spp.
					Gyrodinium sp. or *Nematodinium* sp.
					Oxyrrhis marina
			Noctilucales	Noctilucaceae	*Noctiluca scintillans* (*Noctiluca miliaris*)
			Gonyaulacales	Ceratiaceae	*Ceratium furca*
					Ceratium fusus
					Ceratium lineatum
					Ceratium massiliense
					Ceratium breve
					Ceratium tripos
					Ceratium trichoceros
					Ceratium spp.
				Cladopyxidaceae	*Cladopyxis* sp.
				Goniodomataceae	*Goniodoma polyedricum*
					Pyrodinium sp.
					Alexandrium sp.
				Gonyaulacaceae	*Gonyaulax* spp.
				Pyrocystaceae	*Pyrocystis obtusa*
					Pyrocystis sp.
				Pyrophacaceae	*Pyrophacus horologium*
			Peridiniales	Peridiniaceae	*Protoperidinium grande*
					Protoperidinium cf. *cerasus*
					Protoperidinium cf. *pyriforme*
					Protoperidinium cf. *depressum*
					Protoperidinium cf. *cerasus*
					Protoperidinium cf. *murrayi*
					Protoperidinium cf. *trochoideums*
					Protoperidinium cf. *diabolum*
					Protoperidinium pentagonum
					Protoperidinium cf. *curtipes*
					Protoperidinium cf. *conicum*
					Protoperidinium spp.

Phylum	Class	Sub-Class	Order	Family	Genus and Species
					Peridinium spp. *Podolampas palmipes* *Podolampas* cf. *bipes*

OTHERS

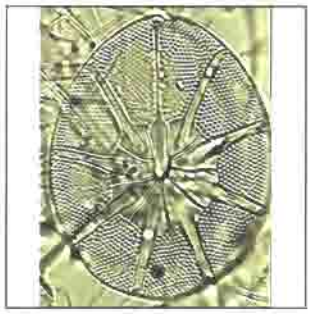
Phylum	Class	Sub-Class	Order	Family	Genus and Species
Chrysophyta Prymnesiophyta (Haptophyta)	Dictyochophyceae (Silicoflagellata) Coccolithophorida (Prymnesiophyceae)		Dictyochales Coccosphaerales Prymnesiales	Dictyophyceae Coccolithaceae Phaeocystaceae	*Dictyocha fibula* *Distephanus speculum* Coccolithophores *Phaeocystis* sp.

Phylum	Class	Sub-Class	Order	Family	Genus and Species
Cyanophycota	Cyanophyceae		Nostocales	Oscillatoriaceae	*Trichodesmium erythraeum* *(Oscillatoria erythraea)*





Amphiprora sp.



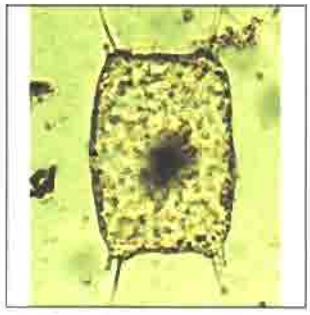
Asterolampra sp.



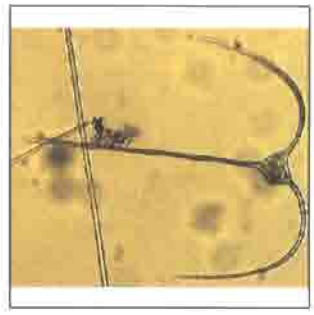
Bacteriastrum sp.



Bellerochea horologicalis



Biddulphia (Odontella) sp.



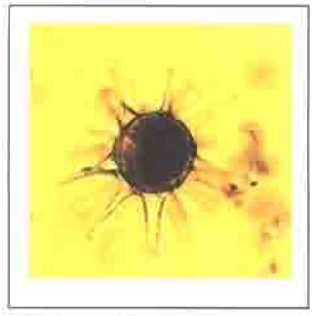
Ceratium sp.



Coscinodiscus sp.



Chaetoceros sp.



Cladopyxis sp.



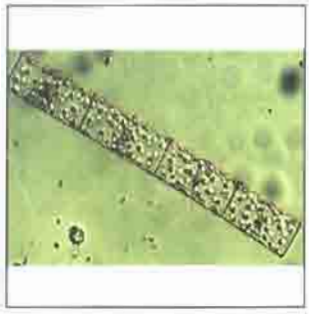
Dinophysis caudata



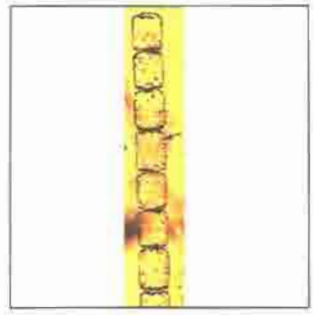
Eucampia zoodiacus



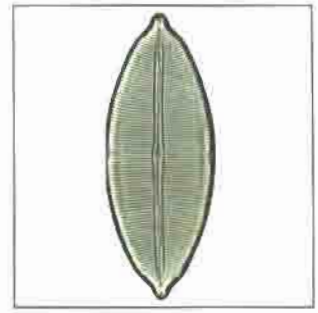
Goniaulax sp.



Guinardia sp.



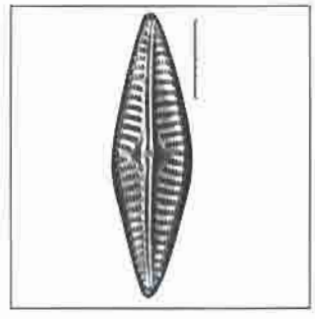
Lauderia sp.



Mastogloia sp.



Nitzschia longissima



Navicula sp.



Nitzschia sp.



Ornithocerous sp.



Peridinium grande



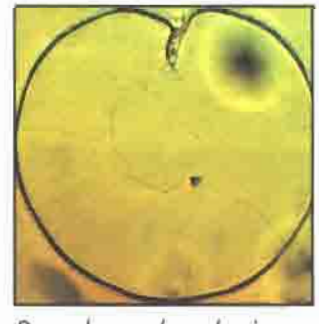
Peridinium sp.



Pleurosigma sp.



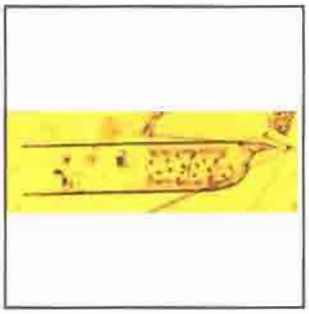
Prorocentrum sp.



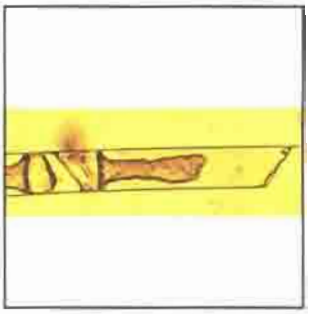
Pyrophacus horologium



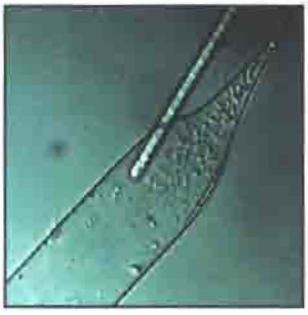
Rhizosolenia alata



Rhizosolenia cochlea



Rhizosolenia imbricata



Rhizosolenia sp.



Surirella fastuosa



Triceratium favus

Electron Micrographs



Navicula sp.



Lyrella sp.



Lauderia annulata

Photos by Manal Al-Kandari

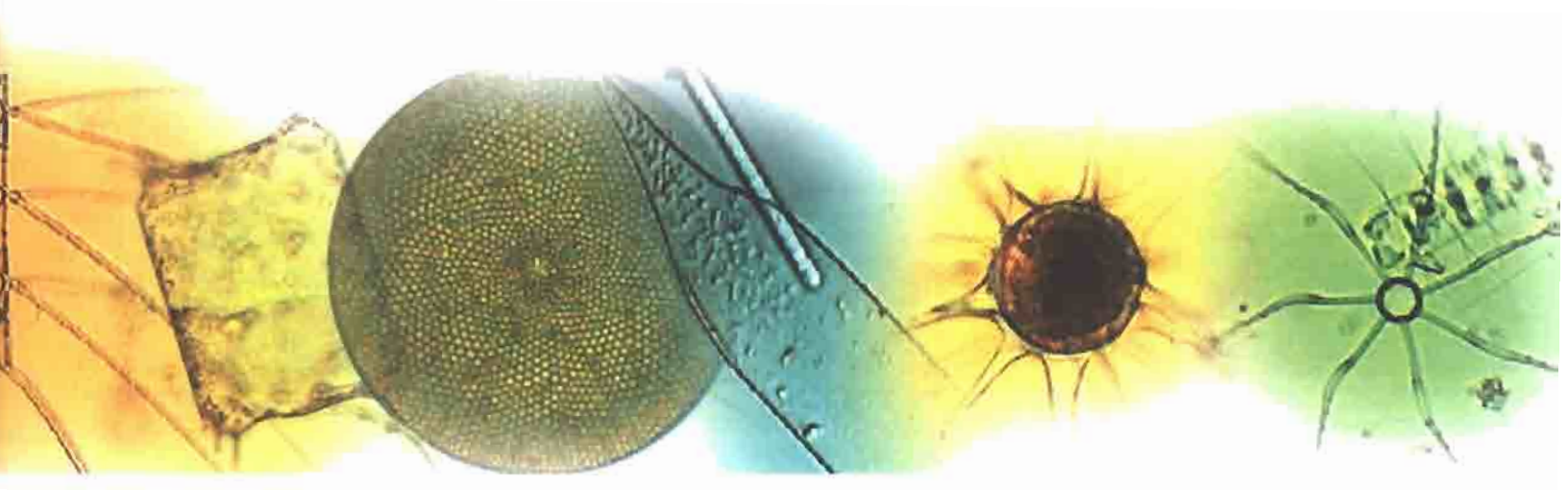


Red Tide. Several species of phytoplankton bloom in Kuwait's waters and form what is known as a red tide (Fig. 88). Examples of these species are *Myrionecta rubra (Mesodinium rubrum)*, *Prorocentrum mexicanum*, *Karenia (Gymnodinium) selliforme*, *Nitzschia* spp., *Rhizosolenia* spp., *Trichodesmium (Oscillatoria) erythraeum*, *Coscinodiscus* spp., *Gymnodinium impudicum*, *Phaeocystis* sp., *Cylindrotheca closterium*, *Karenia brevis (formerly, Gymnodinium breve)*, and others. In general, most previously documented blooms in Kuwait's waters were not harmful, except for one incident of *Karenia selliforme and Prorocentrum mexicanum* that occurred in the summer of 1999, causing significant fish mortality.

Other potentially harmful phytoplankton species that occur in Kuwait's waters could bloom under the proper environmental conditions (e.g., *Asterionella glacialis*, *Chaetoceros coarcatus*, *Chaetoceros decipiens*, *Peudonitzschia multiseries*, *Ceratium furca*, *Ceratium fusus*, *Ceratium trichoceros*, *Dinophysis caudata*, *Dinophysis acuminata*, *Dinophysis acuta*, *Prorocentrum micans*, *Noctiluca miliaris*).



Fig. 88. ***Trichodesmium erythraeum (Oscillatoria erythraea)*** *bloom in Kuwait's waters (photo by Abdul Rahman Abdul Ghaffar).*



Zooplankton. Intense zooplankton surveys have been conducted in Kuwait's waters (e.g., Jacob et al., 1979, 1981; Dames and Moore, 1983; Michel, 1983; Houde et al., 1986; Lee et al., 1990; Al-Yamani et al., 1997a,b). Zooplankton biomass (sampled with 110 um net) ranges from 0.14 in southern waters to 0.86 g/m^3 in Kuwait Bay. Zooplankton biomass is higher in Kuwait Bay (> 0.3 g/m^3) than in the southern and offshore waters. There is spatial and temporal variability in the abundance and distribution of the different zooplankton groups (Michel et al., 1986).

Mean total zooplankton abundance in Kuwait's waters (sampled with 110 µm nets) for 1996/1997 was $3X10^5$ individuals/m^3. The range of mean abundances of total zooplankton in Kuwait's waters was from 31,500 to 360,294 individuals/m^3 for the period 1999-2001. A minimum abundance value of 6029/m^3 was found off a sewage outlet in Kuwait Bay followed by another minimum of 7101/m^3 in the northern turbid waters of Khor Al-Sabbiya, whereas maximum abundance value of 3,024,586/m^3 was found in the waters east of Failaka Island.

In Kuwait's waters, 26 species of hydromedusae, 40 of copepods and seven of chaetognaths were identified (Michel et al., 1986). The 17 most encountered zooplankton groups (sampled with 110 um nets) included copepod nauplii, copepodites and adults; chaetognaths; cladocerans; gastropod larvae; larvaceans, pelecypod larvae; decapod larvae; ostracods; tintinnids; polychaete larvae; echinoderm larvae; medusae; crab zoea; siphonophores; invertebrate eggs; *Noctiluca*; and fish larvae (Al-Yamani et al., 1997a,b). Spatial and seasonal variations in the abundance of selected groups of zooplankton for the year 1996/1997 are displayed in Figs. 89-100. Copepods (nauplii, copepodites and adults) are the most abundant zooplankton group (about 77% composition) in Kuwait's waters. Copepods include calanoid, cyclopoid, harpacticoid and poecilostomatoid groups (orders). In general, calanoid copepods dominate the copepod population in the northern waters of Kuwait and off Kuwait Bay, but, at times (e.g., August 1996), cyclopoids dominate in the southern waters (Al-Yamani et al., 1997b). The calanoid copepod *Parvocalanus crassirostris* (formerly referred to as *Paracalanus crassirostris* in Michel et al., 1986) is one of the most abundant copepod species in Kuwait's waters. *Acartia pacifica* co-dominates with *P. crassirostris* in



Fig. 89. Temporal and spatial distribution of total zooplankton in Kuwait's waters.

Khor Al-Sabbiya waters, but its abundance is reduced in the southern offshore waters of Kuwait (AL-Yamani and Prusova, 2003). Other common copepods in Kuwait's waters are *Oithona simplex*, *Oithona attenuata*, *Euterpina acutifrons*, *Corycaeus* spp. and *Acrocalanus gibber*, among others. Different zooplankton community compositions occur at the different localities in Kuwait's waters. Foraminiferans occasionally appear to be very abundant in northern waters of Kuwait. Pelecypod (bivalve mollusks) and gastropod larvae (snail-like mollusks) are more numerous in the southern waters, especially off Al-Khiran.

Grabe and Lees (1992) identified six planktonic penaeids (penaeid larvae) from Kuwait's waters using plankton nets of 202-505 µm mesh size. The sergestids, *Lucifer hanseni* and *Acetes japonicus*, were the two most numerically abundant species in these waters. The most abundant penaeid larvae were *Parapenaeopsis stylifera* and *Metapenaeus* spp. Grabe and Lees (1992) indicated that Khor Al-Sabbiya might serve as a nursery habitat for the two penaeids *Metapenaeus* spp. and *Penaeus semisulcatus*.

Holoplankton is always more numerous than the meroplankton in Kuwait's waters, and is dominated by copepods. The numbers of zooplanktonic groups and the diversity of species are high in Kuwait's waters; however, the majority of the zooplankton species are present in low numbers (Michel et al., 1986). Zooplankton and phytoplankton, especially copepods and diatoms, are important food sources for fish larvae as well as adult fishes, such as suboor, zobaidy and others. Indirect proof of the richness of zooplankton in Kuwait's waters is the regular presence of whale sharks, the world's largest fish. These magnificent fish have been recorded almost every summer in Kuwait's offshore waters since the 1991 Gulf War.

Incursions of oceanic waters due to the counterclockwise circulation of the Arabian Gulf waters are evident by the periodic appearance of typically offshore species at some offshore stations in Kuwait's waters, e.g., *Cavolinia longirostris*, *Sagitta bedfordii*, *Oncaea conifera*, *Sagitta regularis* and *Krohnitta subtilis* (Michel et al., 1986).



A whale shark in Kuwait's waters (photo by Shaker Al-Hazeem).



Fig. 90. Temporal and spatial distribution of total nauplii in Kuwait's waters.

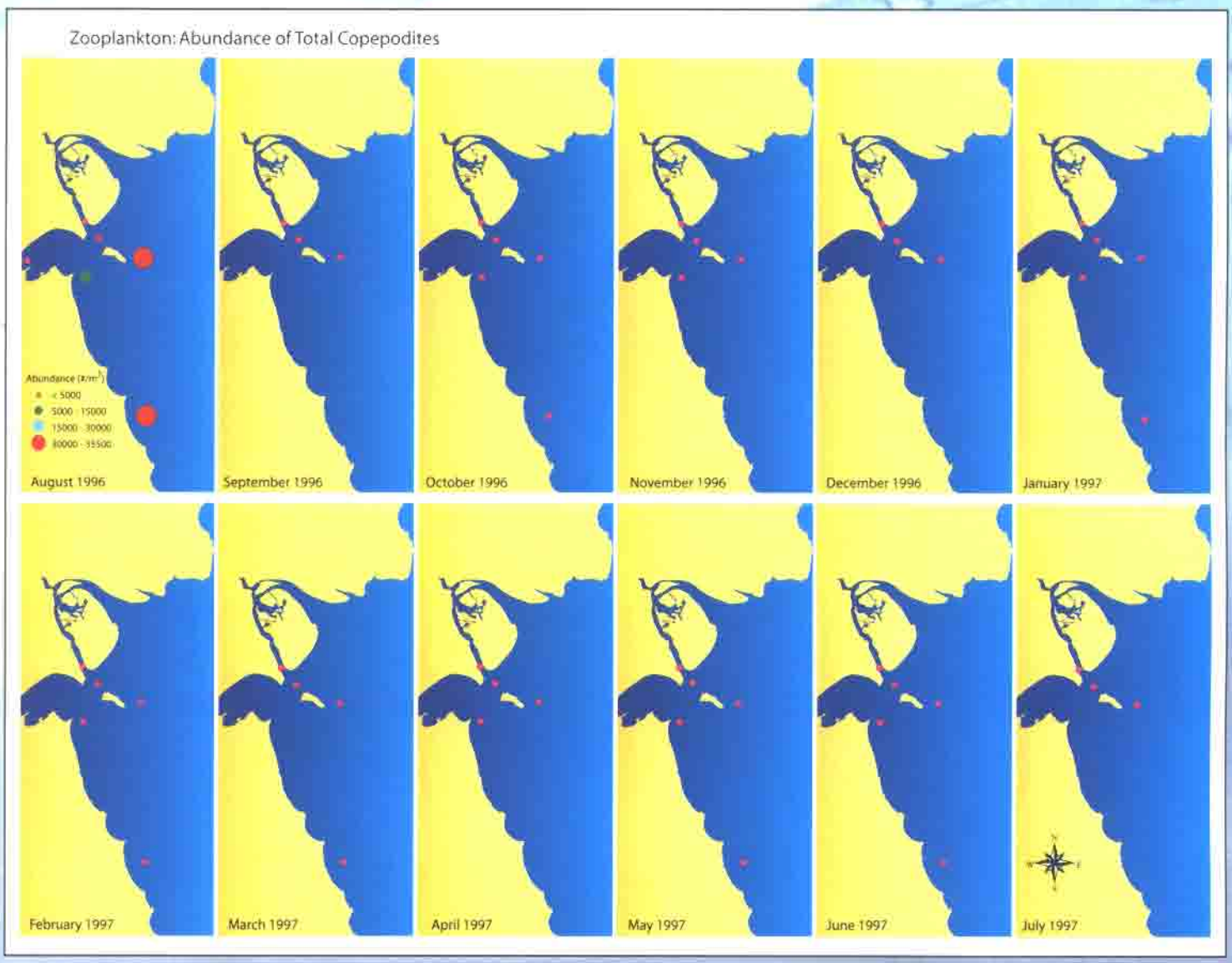


Fig. 91. Temporal and spatial distribution of total copepodite copepods in Kuwait's waters.



Fig. 92. Temporal and spatial distribution of total calanoid copepods in Kuwait's waters.

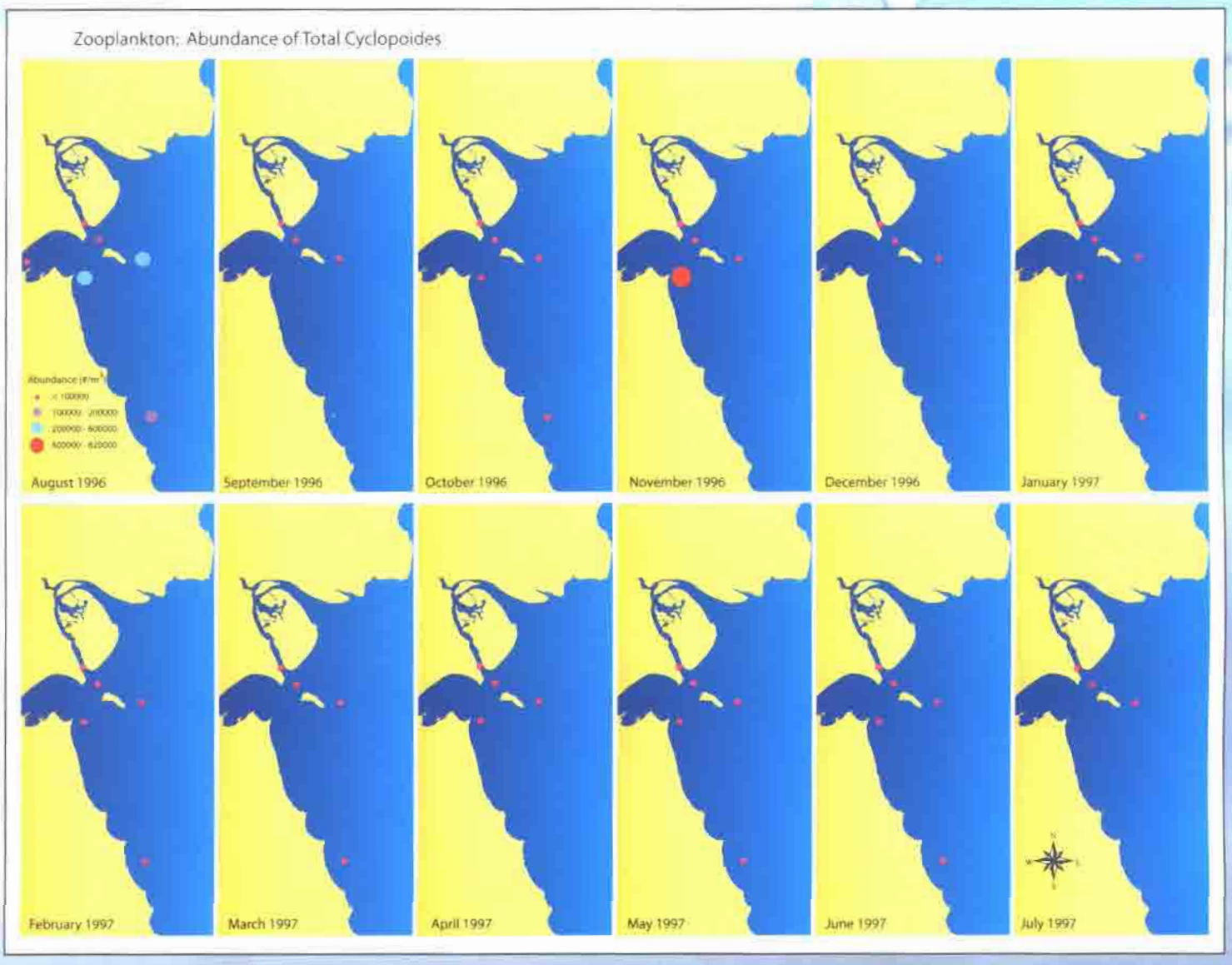


Fig. 93. Temporal and spatial distribution of total cyclopoid copepods in Kuwait's waters.

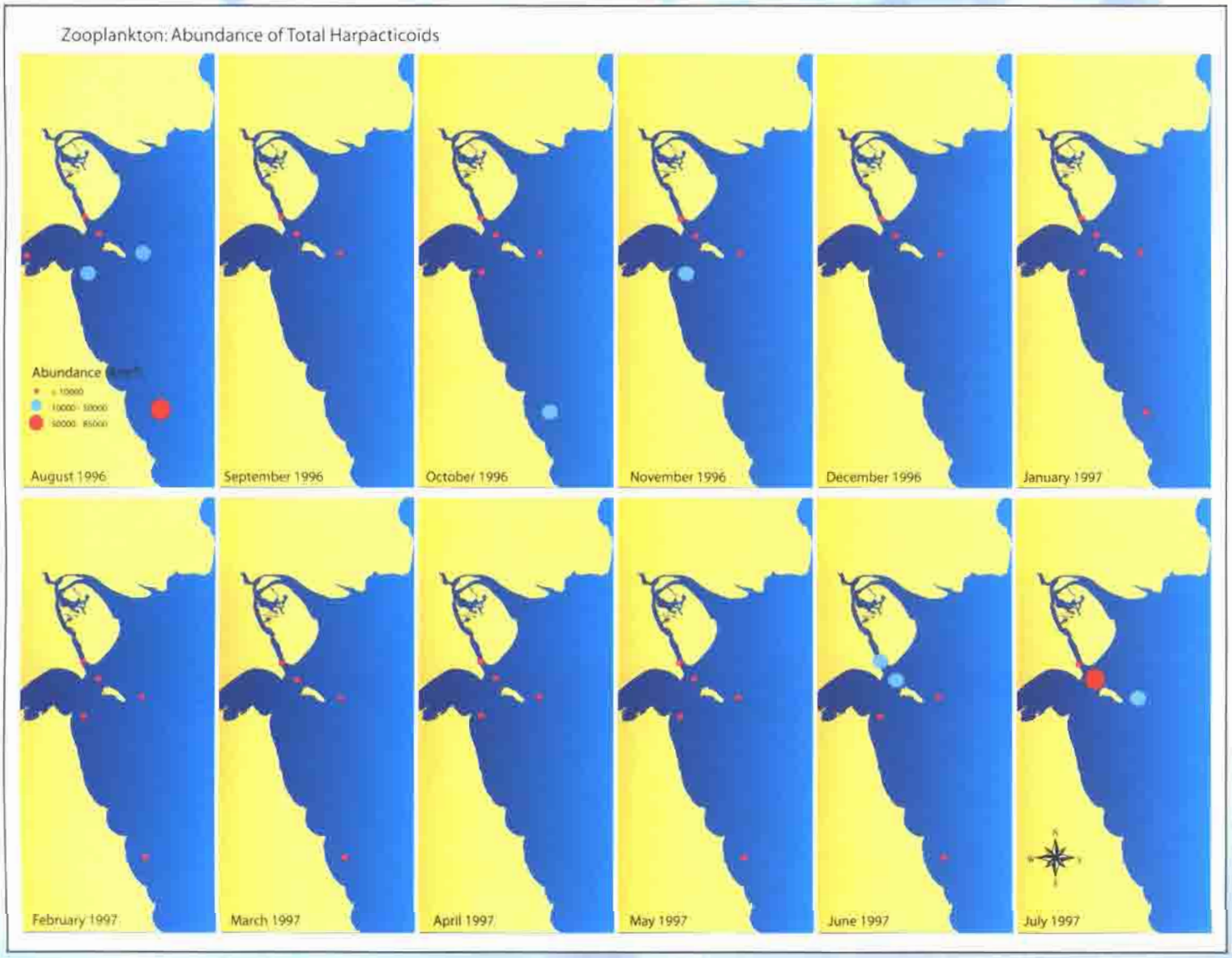


Fig. 94. Temporal and spatial distribution of total harpacticoid copepods in Kuwait's waters.



Fig. 95. Temporal and spatial distribution of total foraminifera in Kuwait's waters.



Fig. 96. Temporal and spatial distribution of total shrimp postlarvae in Kuwait's waters.

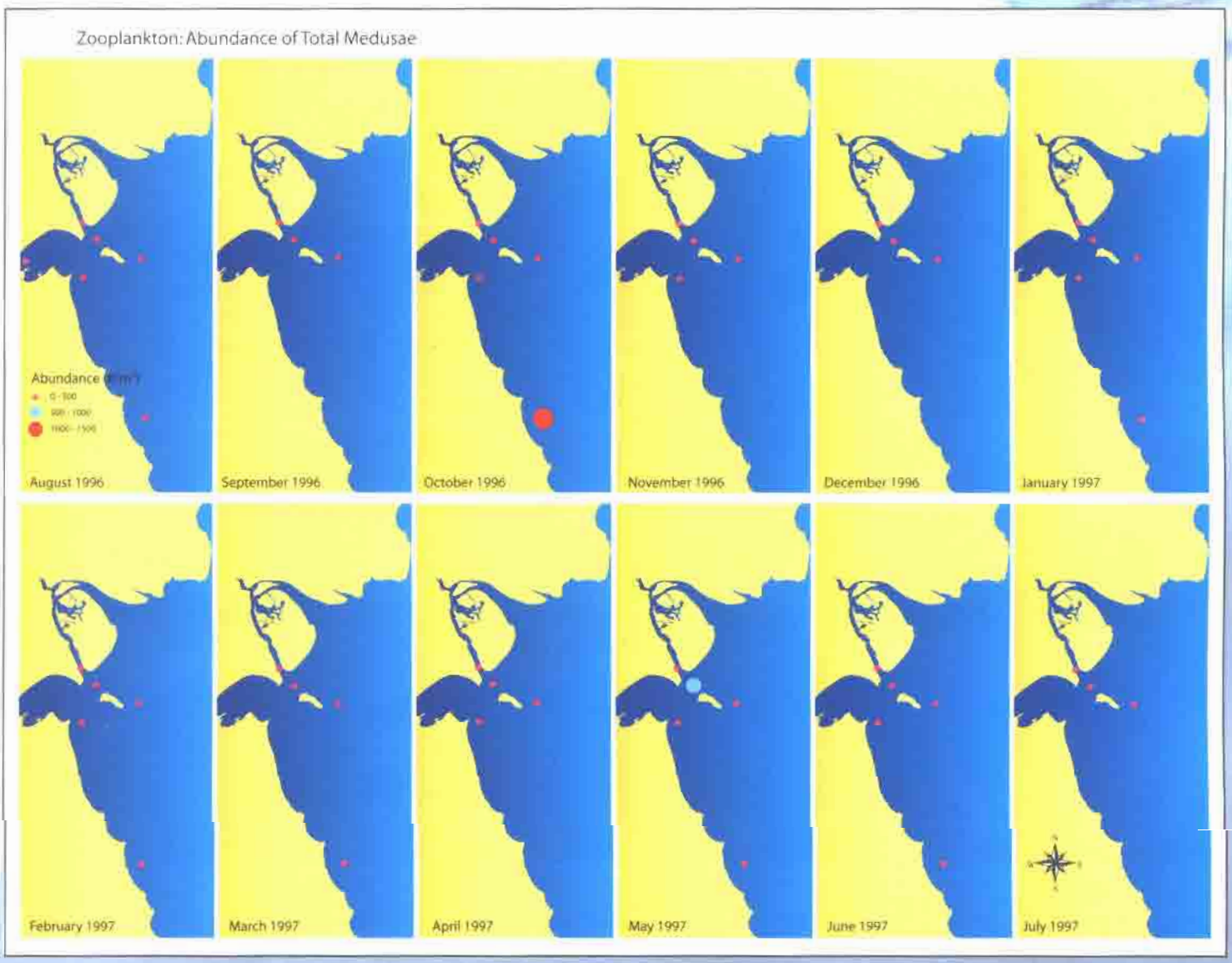


Fig. 97. Temporal and spatial distribution of total medusae in Kuwait's waters.



Fig. 98. Temporal and spatial distribution of total ctenophores in Kuwait's waters.



Fig. 99. Temporal and spatial distribution of total crustacean decapod larvae in Kuwait's waters.



Fig. 100. Temporal and spatial distribution of total cladocera in Kuwait's waters.

A list of zooplankton organisms occurring in Kuwait's waters is presented below.

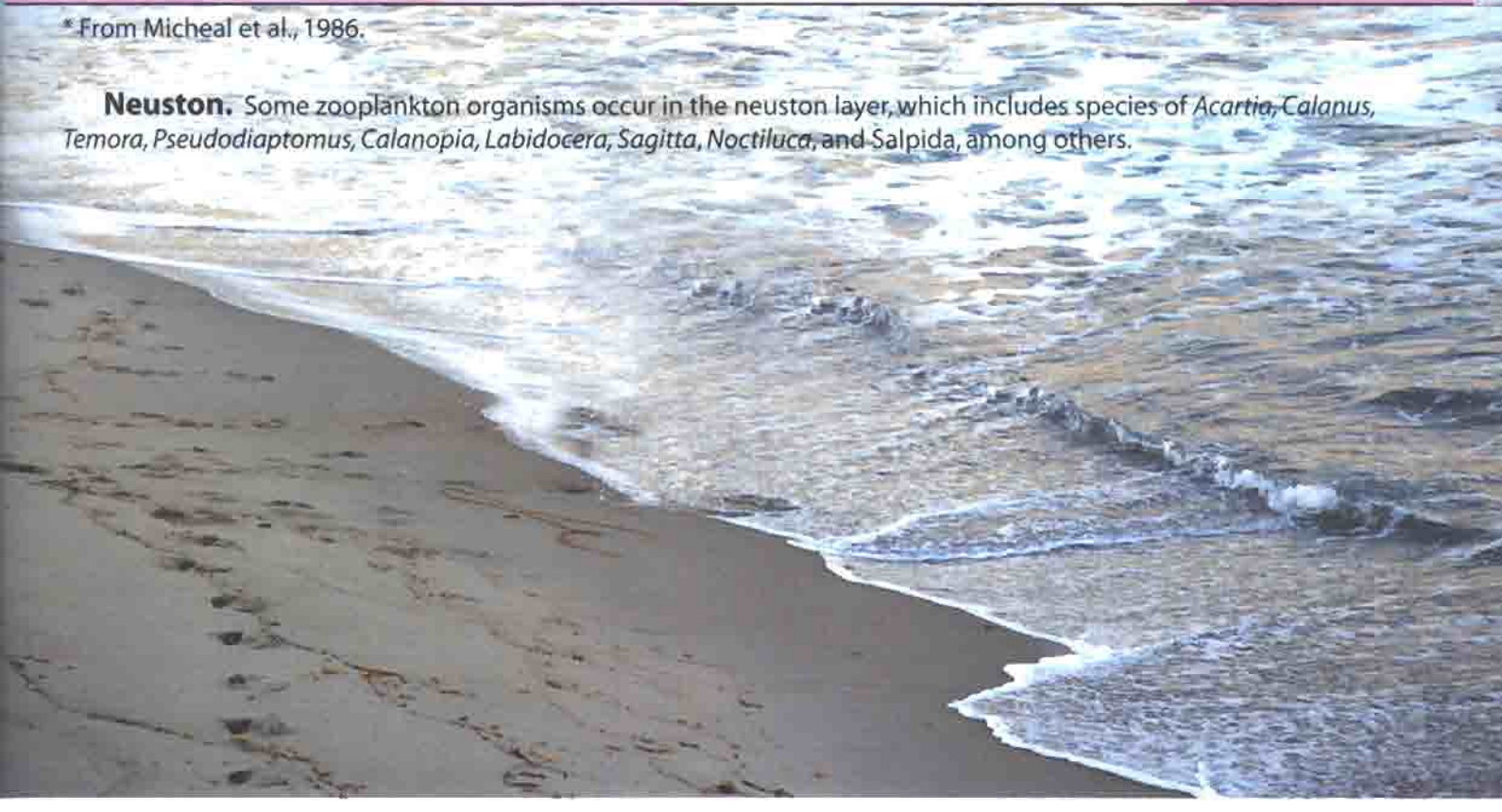
Phylum	Class	Order	Family	Genus and Species	General Group/Larvae
Granuloreticulosa	Foraminifera	Globigerinida	Globigerinidae		
Actinopoda	Acantharia				
Ciliophora	Polyhymenophorea	Oligotrichida	Tintinnididae	*Leprotintinnus nordqvisti*	
			Codonellidae	*Tintinnopsis cylindrica*	
				Tintinnopsis mortensenii	
				Tintinnopsis parvula	
				Tintinnopsis tocantinensis	
				Tintinnopsis spp.	
				Codonellopsis ostenfeldi	
				Codonellopsis spp.	
			Cyttarocylidae	*Favella panamensis*	
			Petalotrichidae	*Metacylis* spp.	
			Rhabdonellidae	*Rhabdonella spiralis*	
			Tintinnidae	*Eutintinnus* sp.	
	Haptoria	Haptorida	Mesodiniidae	*Myrionecta rubra* (*Mesodinium rubrum*)	
Dinoflagellata	Noctiluciphyceae	Noctilucales	Noctilucaceae	*Noctiluca scintillans*	
Cnidaria	Hydrozoa	Anthomedusae	Corymorphidae	*Euphysora bigelowi* *	
				Euphysora normani *	
			Tubulariidae	*Hybocodon forbesi* *	
			Bougainvilliidae	*Koellikerina octonemalis* *	
			Pandeidae	*Amphinema rugosum* *	
				Pandeopsis ikarii *	
		Leptomedusae	Laodiceidae	*Staurodiscus vietnamensis* *	
			Campenulariidae	*Obelia* sp. *	
				Phialucium carolinae *	
				Octophialucium indicum *	
				Octophialucium medium *	
			Eirenidae	*Eirene ceylonensis* *	
				Eirene viridula *	
				Eirene kambara *	
				Eirene hexanemalis *	
				Eirene menoni *	
				Eirene palkensis *	
				Eutima levuka *	
			Aequoridae	*Aequorea aequorea* *	
				Aequorea parva *	
				Aequorea pensilis *	
		Olindiadidae	Olindiasidae	*Olindias singularis* *	
		Trachimedusae	Geryonidae	*Liriope tetraphylla* *	
			Rhopalonematidae	*Agulaura hemistoma* *	
		Narcomedusae	Aeginidae	*Solmundella bitentaculata* *	
			Cuninidae	*Cunina octonaria* *	
		Siphonophora	Diphyidae	*Diphyes chamissonis*	
				Lensia spp.	
	Scyphozoa	Semaeostomeae		*Sanderia malayensis* *	
	Anthozoa				Anthozoan larvae *
Ctenophora	Tentaculata	Cidippida	Pleurobrachiidae	*Pleurobrachia pileus* *	
		Lobata	Mnemiidae	*Mnemiopsis* sp. *	
			Ocyropsidae	*Ocyropsis* sp. *	
	Nuda	Beroida	Beroidae	*Beroe* sp. *	
Platyhelminthes	Turbellaria	Polycladida			
Rhynchocoela					Pilidium larvae *
Ectoprocta					Cyphonautes larvae

Phylum	Class	Order	Family	Genus and Species	General Group/Larvae
Phoronidae					Actinotroch larvae
Brachiopoda					Larvae of *Lingula* sp.*
Annelida	Polychaeta				Setigerous larvae
Mollusca	Bivalvia				Veliger larvae
	Gastropoda				Veliger larvae
		Sorbeoconcha	Atlantidae	*Atlanta pacifica*	
		Thecosomata	Cavoliniidae	*Creseis cherchiae*	
				Creseis acicula *	
				Cavolinia longirostris *	
		Gymnosomata	Pneumodermatidae		
Arthropoda	Crustacea	Cladocera	Sididae	*Penilia avirostris*	
			Podonidae	*Pleopis polyphemoides*	
				Podonevadne trigona	
				Evadne anonyx (?)	
	(Subclass: Ostracoda)	Myodocopida	Halocyprididae	*Euconchoecia aculeata* *	
			Cypridinidae	*Cypridina* sp. *	
	(Subclass: Copepoda)	Calanoida	Calanidae	*Canthocalanus pauper*	
			Eucalanidae	*Subeucalanus flemingeri*	
				Subeucalanus subcrassus	
			Clausocalanidae	*Clausocalanus minor*	
			Paracalanidae	*Acrocalanus gibber*	
				Paracalanus sp.	
				Parvocalanus crassirostris	
			Centropagidae	*Centropages tenuiremis*	
				Centropages furcatus	
			Candaciidae	*Candacia bradyi*	
				Candacia spp.	
			Pseudodiaptomidae	*Pseudodiaptomus arabicus*	
			Acartiidae	*Acartia pacifica*	
				Acartia amboinensis	
			Temoridae	*Temora turbinata*	
				Temora discaudata	
			Tortanidae	*Tortanus forcipatus*	
			Pontellidae	*Labidocera minuta*	
				Labidocera spp.	
				Calanopia minor	
				Calanopia elliptica	
		Cyclopoida	Oithonidae	*Oithona attenuata*	
				Oithona simplex	
				Oithona plumifera	
				Oithona spp.	
		Harpacticoida	Euterpinidae	*Euterpina acutifrons*	
			Ectinosomatidae	*Microsetella* sp.	
			Miraciidae	*Macrosetells gracilis*	
			Clytemnestridae	*Clytemnestra scutellata*	
		Poecilostomatoida	Oncaeidae	*Oncaea clevei*	
			Corycaeidae	*Corycaeus*	
				(Dithrichocorycaeus) andrewsi	
				Corycaeus	
				(Dithrichocorycaeus) dahli	
				Corycaeus	
				(Dithrichocorycaeus) lubbocki	
				Corycaeus	
				(Onychocorycaeus) agilis	
				Corycaeus	
				(Onychocorycaeus) pacificus	

Phylum	Class	Order	Family	Genus and Species	General Group/Larvae
			Sapphirinidae	*Sapphirina nigromaculata*	
		Monstrilloida	Monstrillidae	*Cymbasoma longispinosum**	
	(Subclass: Cirripedia)				Nauplii and Cypris larvae
	(Subclass: Malacostraca)	Decapoda	e.g., Portunidae	e.g., *Portunus pelagicus*	Crab zoea and megalops larvae
			e.g., Scyllaridae	e.g., *Thenus orientalis**	Phyllosoma larvae
			Penaeidae		Penaeid protozoea, mysis and postlarvae
			Luciferidae	*Lucifer hanseni*	
Echinodermata	Crinoidea				Doliolaria larvae *
	Holoturoidea				Auricularia larvae *
	Asterioidea				Brachiolaria larvae *
	Ophiuroidea				Ophiopluteus larvae *
	Echinoidea				Echinopluteus larvae *
Chaetognatha	Sagittoidea	Aphragmophora	Sagittidae	*Sagitta enflata*	
				Sagitta bedfordii *	
				Sagitta bedfordii *	
				Sagitta neglecta *	
				Sagitta pulchra *	
				Sagitta regularis *	
				Sagitta spp.	
			Krohnittidae	*Krohnitta pacifica* *	
				Krohnitta subtilis *	
Hemichordata	Enteropneusta				Tornaria larvae *
Chordata	Thaliacea	Doliolida	Doliolidae	*Doliolum* sp. *	
		Salpida	Salpidae	*Pegea conifera* *	
				Weelia cylindrica *	
	Larvacea	Copelata	Oikopleuridae	*Oikopleura dioica*	
				Oikopleura spp.	
Cephalochordata			Branchiostomidae	*Branchiostoma* sp. *	

* From Micheal et al., 1986.

Neuston. Some zooplankton organisms occur in the neuston layer, which includes species of *Acartia, Calanus, Temora, Pseudodiaptomus, Calanopia, Labidocera, Sagitta, Noctiluca,* and Salpida, among others.





A *Pleopis* cladoceran



Sapphirina nigromaculata



Polychaete larva



Acartia pacifica



Tintinnopsis (Tintinnid)



Corycaeus dahli



A *Penilia* cladoceran



Euchaeta concinna



An *Oikopleura* larvacean



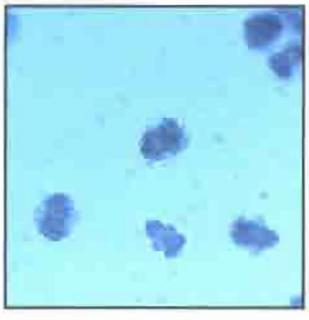
Favella (Tintinnid)



Labidocera minuta



Podonevadne sp.



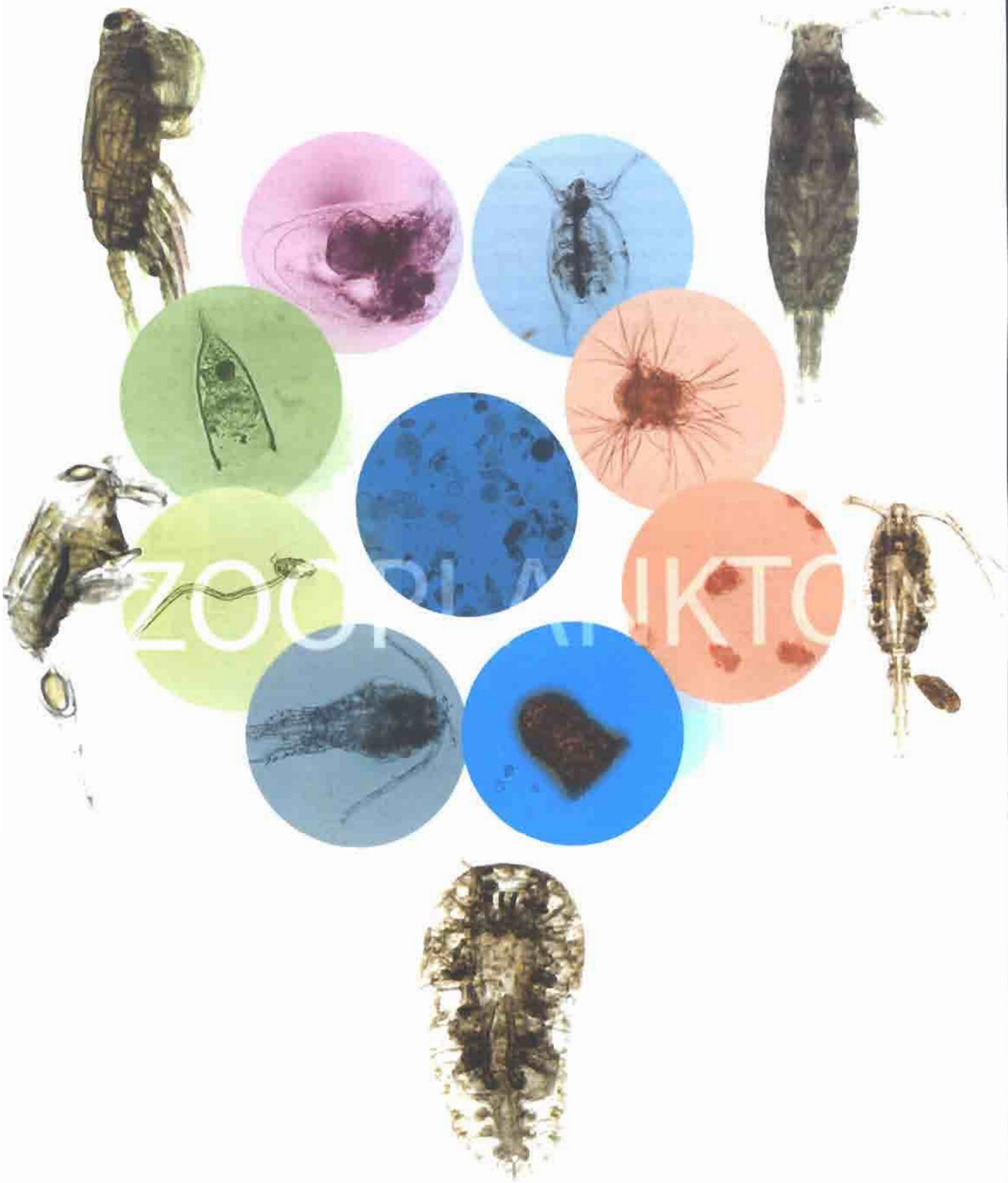
Myrionecta rubra
(Mesodinium rubrum)



Oithona plumifera

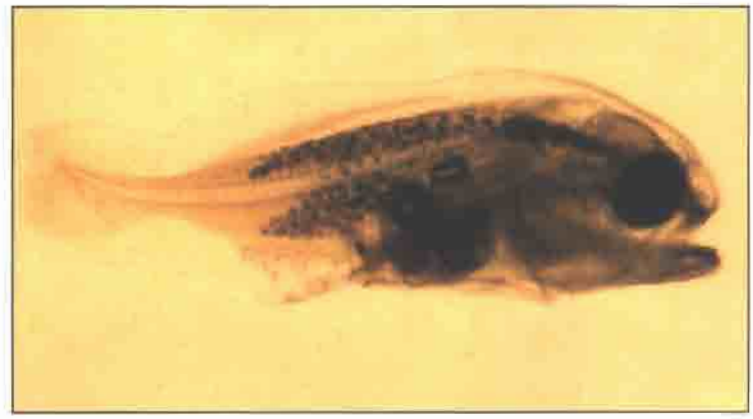


Copepod fecal pellet



Photos by Drs. Faiza Y. Al-Yamani and Irina Prusova.

Ichthyoplankton (Fish Larvae).



Zobaidy larva (photo by Tawfiq Abu-Rizq).

Grabe et al. (1992) identified 50 larval fish taxa from Kuwait's waters. They found dominant families to be Sparidae-type larvae, in addition to larvae of clupeids and gobies. The predominant families of fish larvae in the western Arabian Gulf according to Houde et al. (1986) were Engrauilidae, Gobiidae and Clupeidae, which accounted collectively for about 42.5% of all fish larvae collected. A total of 53 families of fish larvae were identified, including 41 genera, 24 species and 84 specific types of larvae. Houde et al. (1986) described the spatial and temporal distribution of larval fish in Kuwait's waters. They found a distinct seasonal abundance in the occurence of larval fish. Most fishes were found to spawn in Kuwait's waters during the warm months from late spring to early fall. Most of the spawning was by the abundant Engraulidae (anchovies), Gobiidae (gobies) and Clupeidae (herrings). The number of fish larvae taxa and total larval abundance in Kuwait Bay peaked during late spring and were lowest in winter (Grabe et al., 1992). Important winter spawners included Haemulidae (grunts), Mugilidae (mullet) and Soleidae (flatfish).



Fig. 101. Temporal and spatial distribution of mean annual abundance of fish eggs and selected groups of larval fish in Kuwait's waters.

The assemblage of ichthyoplankton in Kuwait's waters is moderately diverse. The diversity changes seasonally and differs among the different subareas of Kuwait's waters. Diversity increases in the southern waters of Kuwait. The lowest ichthyoplankton diversity was found in Kuwait Bay and the highest in the offshore waters. Intermediate values were found in the coastal and northern waters. Examples from the results obtained from Dames and Moore's ichthyoplankton study (1983) are displayed in Fig. 101, showing the distribution of fish eggs and selected larvae.

The range of mean abundance of fish larvae (ichthyoplankton) collected with 300 µm mesh nets during 2000-2001 was 36-281/m^3. The minimum abundance recorded was 0.0/m^3 (i.e., they were absent in samples collected on certain days) and maximum abundance recorded was 1419/m^3. In general, peak spawning periods of fish (densities of fish eggs and larvae) correlate well with zooplankton peak abundances (Michel et al., 1986). Larval (nauplii), subadults (copepodites) and adult copepods, and mollusc larvae (bivalve and gastropod veligers) are preferred food items for larval fish. Fish larvae also feed on cirriped larvae, cladocerans, diatoms, tintinnids, pteropods and invertebrate eggs, among others.

Figure 102 displays monthly abundance of total larval fish in Kuwait's waters collected with 300 µm mesh nets. Houde et al. (1986), Grabe et al. (1992) and Lamkin (2002, personal communication) identified the following fish families from Kuwait's ichthyoplankton:

Apogonidae
Belonidae
Blenniidae
Bothidae
Bregmacerotidae
Callionymidae
Carangidae
Clupeidae
Cynoglossidae
Engraulidae
Gobiidae
Haemulidae
Hemiramphidae
Labridae
Leiognathidae
Mugilidae
Mullidae
Pinguipedidae
Platycephalidae
Polynemidae
Pomacentridae
Pomadasyidae
Sciaenidae
Scombridae
Scorpaenidae
Serranidae
Sillaginidae
Soleidae
Sparidae
Stromateidae
Tetraodontidae
Teraponidae
Triacanthidae
Trichiuridae

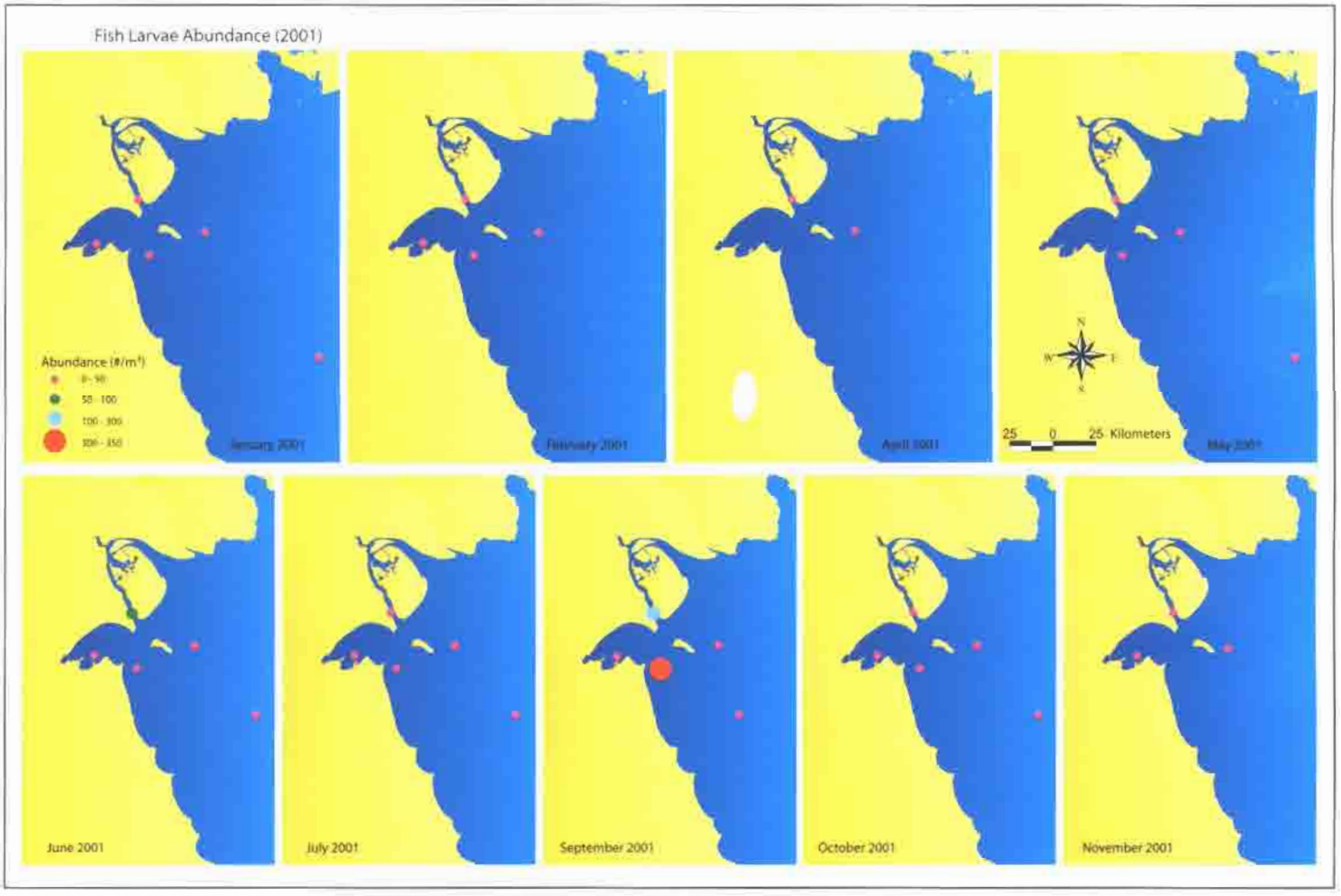
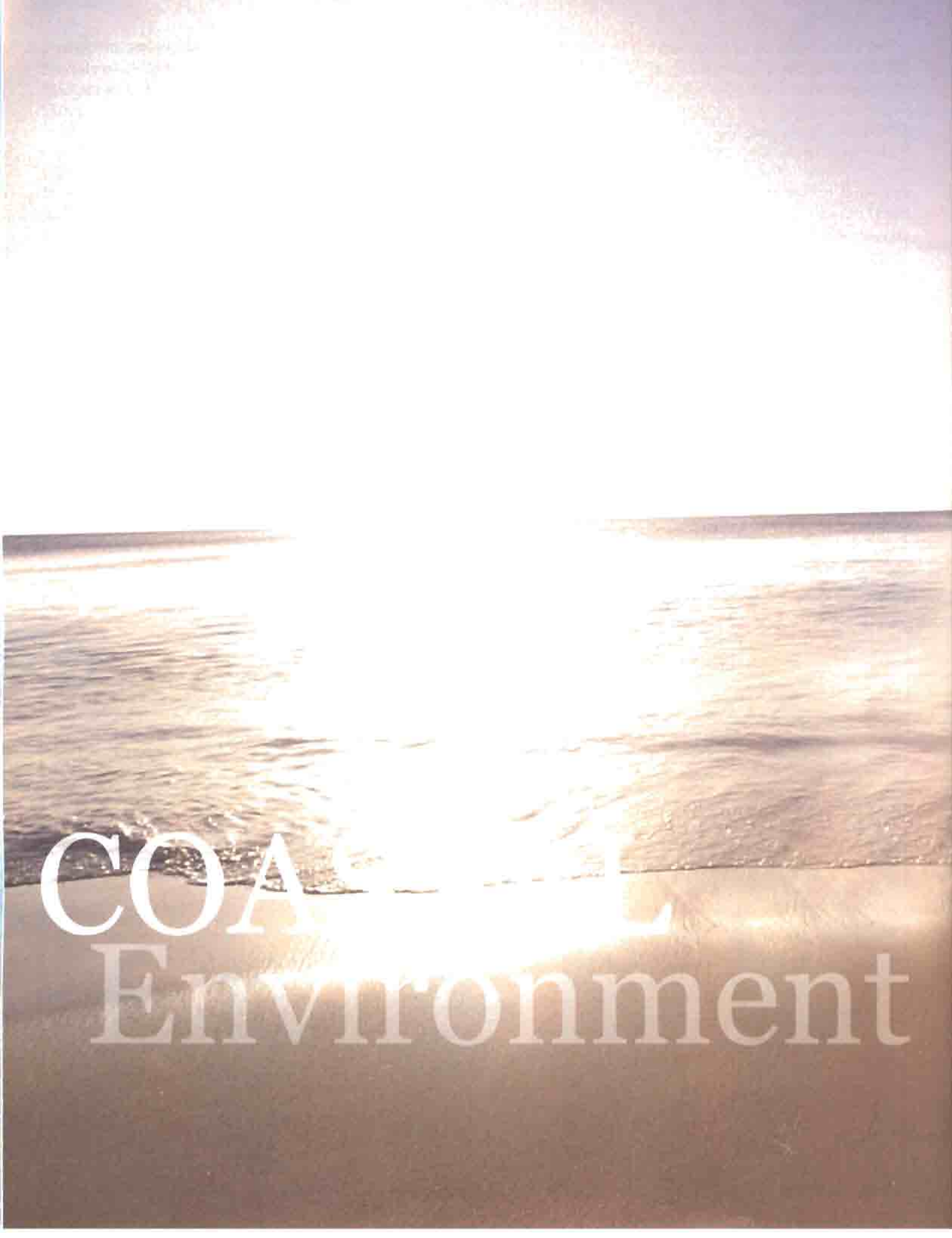
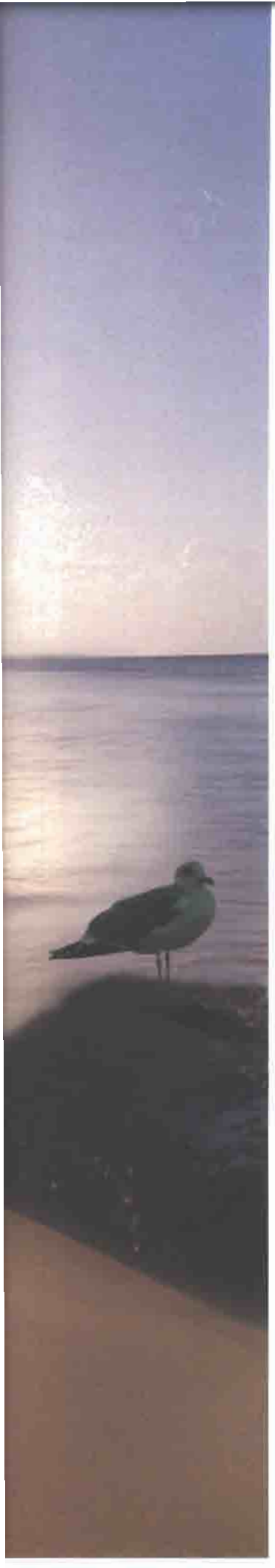


Fig. 102. Temporal and spatial distribution of mean annual abundance of fish larvae in Kuwait's waters.


COAL
Environment



KUWAIT'S COASTAL ENVIRONMENT

Overall

From its border with Iraq in the north to its border with Saudi Arabia in the south, Kuwait's coastline stretches about 180 km (Fig. 103). If the shoreline of Kuwait Bay and other features are taken into account, the length of the land-water interface increases to just over 300 km (excluding island shorelines, such as those of Bubiyan, Failaka, Kubbar, etc.). In general, Kuwait's coastline runs in a NNW direction, but the coasts of Kuwait Bay and Bubiyan island deviate from this trend. Prominent natural features along Kuwait's coast include Kuwait Bay, the Dawhah Peninsula in Kuwait Bay, the islands of Bubiyan and Failaka, Khor Al-Sabbiya, Khor Mufateh (in Al-Khiran), and the cusps at Ras Ajuzah, Ras Al-Ardh, Ras Al-Julaiah and Ras Al-Zour. Kuwait's coast can be conveniently separated into two primary regions. From Kuwait Bay north, intertidal mudflats feature prominently, whereas, south of Kuwait Bay, medium to coarse sand beaches dominate. Within these two broad categories, however, there are several other shoreline types (Fig. 103).

Bubiyan Island

Located in the extreme northwest corner of the Arabian Gulf, Bubiyan ranks as the Gulf's second largest island after Iran's Qeshim Island. Bubiyan (Fig. 103) is part of the deltaic system of the Euphrates, Tigris and Karun Rivers that form the Shatt Al-Arab. The majority of its 917 km^2 is very low, with only coastal dunes of beach sand exceeding 4 m above sea level. Most of the coastline consists of broad intertidal areas, and 44% of the island's 91,700 hectares is inundated by spring tides.

Kuwait Bay

Covering an area of 750 km^2, Kuwait Bay extends westward about 46 km from the Gulf proper. Its widest north-south dimension is 28 km. North Kuwait Bay and Sulaibikhat Bay, a subsystem of Kuwait Bay, both have intertidal mudflats (Fig. 103), which represent some of the most extensive in the entire Gulf (Al-Sarawi et al., 1985). Bishop (1989) calculated that 18,124 hectares of shrimp nursery grounds, most of which are intertidal mudflats, were present in north Kuwait Bay. A horizontal distance of 5 km may separate the edge of the highest and lowest tides in north Kuwait Bay (MOC, 1986). The obvious absence of standing biomass during periods of low tide gives the false impression that mudflats are not productive, and often results in their being among the least appreciated nursery habitats. Juvenile fish, shrimp and other biota follow the tide as it floods and ebbs over the mudflats (Wright et al., 1990; Bishop and Khan, 1999).

As succinctly stated by Peterson and Peterson (1979 p. 63), "intertidal mudflats are most important for what consistently happens on them rather than what is permanently found on them."

In north Kuwait Bay, Wright et al. (1990) found most fish juveniles remained at or just below the low tide mark throughout the tidal cycle, but selected species did follow the tidal front. Kuwait's shrimp juveniles on mudflats have been divided into two groups: intertidal specialists and subtidal specialists (Bishop and Khan, 1999). Their results clearly showed Kuwait's second most important shrimp species, *Metapenaeus affinis*, followed the tidal front as it covered and uncovered the mudflats. Juveniles of other important species remained just at the low tide mark throughout the tidal cycle. Intertidal mudflats are important feeding areas for wading and shore birds, which either stop in Kuwait on their migratory route or overwinter here. The rich intertidal mudflats allow migratory shorebirds to restore expended energy reserves on their fall flights south and spring flights north. Each winter, several hundred Greater Flamingoes overwinter in Kuwait, feeding regularly on the mudflats at or just below the tidal edge.

The northern shore of the Dawhah Peninsula and the south shore of Kuwait Bay are characterized by exposed bedrock platforms and medium to course sand (Al-Sarawi et al., 1985). In late winter and early spring, the intertidal and immediate subtidal areas are covered with benthic algae, mostly *Ulva* and *Enteromorpha*. The presence of these macroalgae species coincides with the main pulse of juvenile *Penaeus semisulcatus* and provides them with an important nursery habitat. Visual inspection of juveniles captured with *Ulva* or *Enteromorpha* show that they are green, the same color as the algae. The color of juvenile *P. semisulcatus* captured with benthic *Sargassum*, a brown alga, is brown, indirect proof that camouflage is a strategy for protection from predation.

Sulaibikhat Bay, a subsystem of Kuwait Bay, ranks among the Gulf's most biologically productive areas. Its fauna are unique in many respects. The Bay's extensive intertidal and immediate subtidal mudflats provide a rich environment for many species, particularly crustacea, mollusks, other benthos, juvenile fishes and migratory birds.

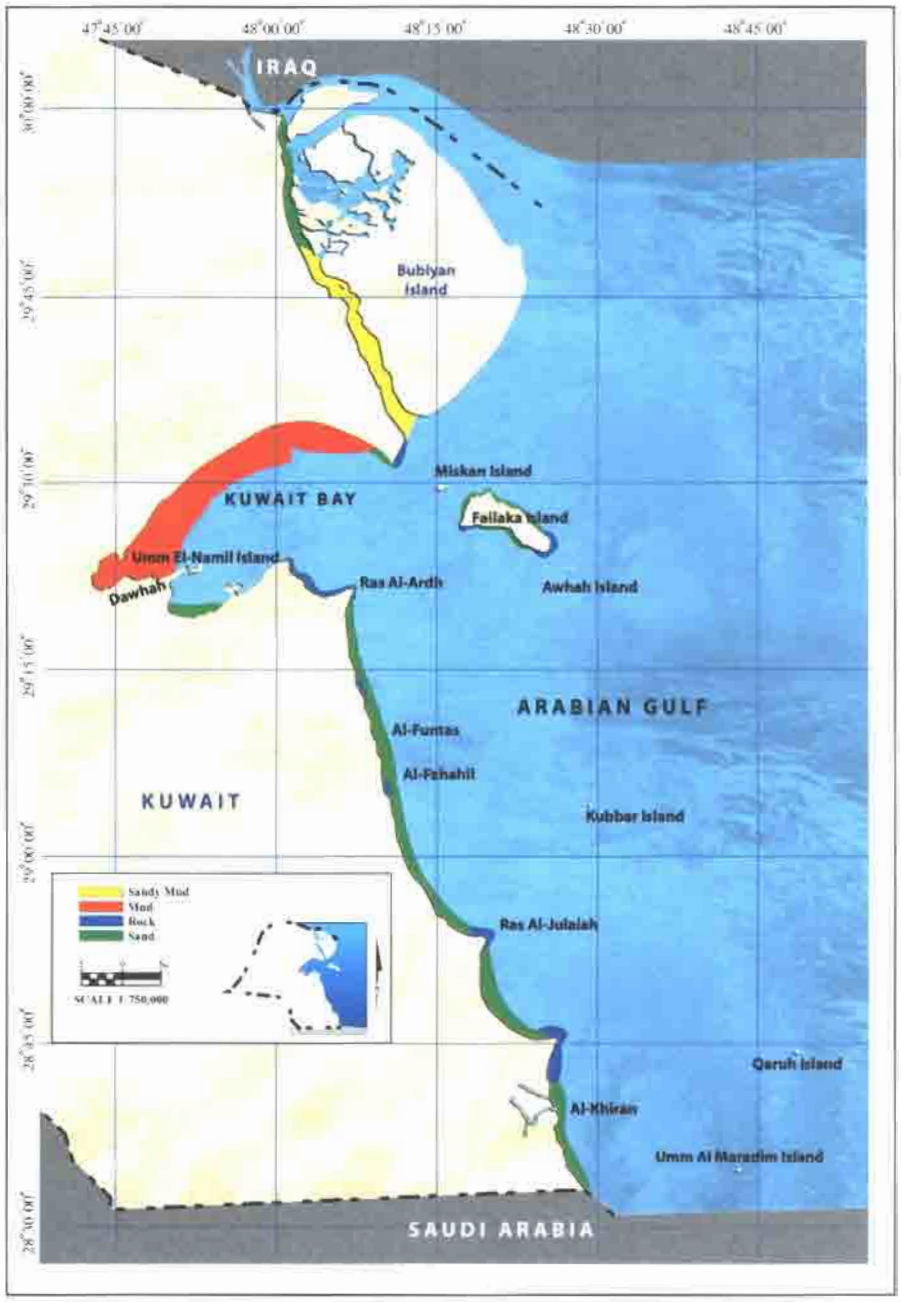


Fig. 103. Different types of shorelines in Kuwait.



*Fig. 104. Polygonal walls of mud constructed by the mudskipper, **Boleophthalmus dussumieri**, in Sulaibikhat Bay, Kuwait (photo by Dr. James Bishop).*

Because of its extensive intertidal areas, a number of zones have been described, each named for the dominant fauna in that zone (Clayton, 1986). The amphibious mudskipper, *Boleophthalmus dussumieri*, delineates its territory by constructing polygonal walls of mud (Fig. 104). This species, which occupies suitable habitats throughout the Indo-Pacific, exhibits this wall-building behavior only in Sulaibikhat Bay, and only in a certain part of Sulaibikhat Bay. Two species of gobies, *Periophthalmus waltoni* and *Scartelaos tenuis*, live sympatrically with *Boleophthalmus*, and two other goby species, *Apocryptodon madurensis* and *Acentrogobius dayi*, live in close association just below the low tide mark. Sulaibikhat Bay has produced two crab species, *Cleisostoma kuwaitense* and *Paracleistostoma arabicum*, new to science (Jones and Clayton, 1983), and specimens of another, *Uca sindensis*, provided material to elevate this former subspecies to specific status (Collins et al., 1984). A fourth species, *Cleistostoma dotilliforme*, was redescribed using material from Sulaibikhat Bay (Jones and Clayton, 1983).



Mudskippers in Sulaibikhat Bay.

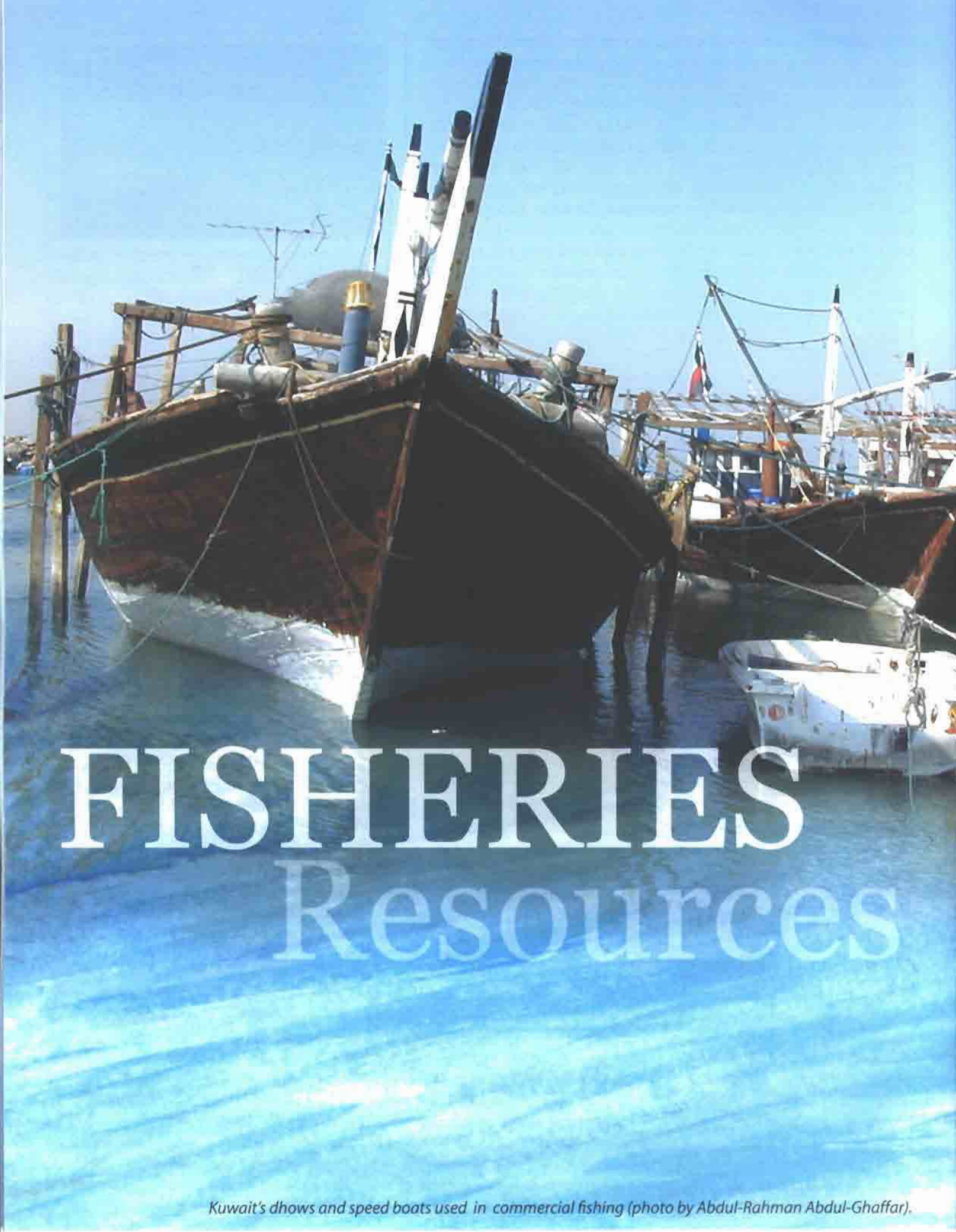
Almost all of Kuwait Bay's southern shoreline has been modified, with more than 638 hectares of land reclaimed and more than 210 hectares of area dredged (Bishop, 1999). The multi-phase Waterfront Development Project has been responsible for filling in much of the intertidal area, and these modifications have greatly reduced the effectiveness of the intertidal zone as a prime nursery habitat. Reclamation not only destroys important nursery habitats, but it also destroys the Bay's ability to provide ecosystem services, such as food production, nutrient removal, recycling, and oxidation and breakdown of organic compounds. If the surfaces of sediment particles in the intertidal zone are taken into account, then the effective surface area of the intertidal zone is many-fold that of the planar distance between high and low tides. Reclamation drastically reduces the ecosystem services provided as the tide ebbs and floods this area twice daily. The annual worth of these services is estimated to be $22,832 per hectare based on the 1994 dollar value (Costanza et al., 1997). Assuming an annual inflation rate of 3%, the 2002 value would approach $30,000 per hectare. Consequently, Kuwaiti society is deprived of U.S. $19 million annually just on ecosystem services alone in Kuwait Bay.

Kuwait's Coast South of Kuwait Bay

With less protection from the open Gulf, wave energy has more of an influence on the coast south of Kuwait Bay and sand beaches dominate. Exposed bedrock is also present, especially just north of Al-Funtas (Al-Sarawi et al., 1985). From Ras Al-Ardh to Ras Al-Julaiah (Fig.103), medium to coarse sand dominates the upper beach material, and south of Ras Al-Julaiah, the upper beach is fine sand. South of the inlet at Al-Khiran, the lower beach is comprised of hard sand or mud (Al-Sarawi et al., 1985).

Almost all of Kuwait's coast south of Kuwait Bay has been modified. From the border with Saudi Arabia to Kuwait City, Al-Sarawi et al. (1995) documented 843 illegal structures, including boat ramps, small harbors, piers, jetties, retaining walls and wave breakers. This is in addition to legal structures. Kuwait is a maritime nation, and the majority of exports and imports depend on shipping. Two major ports serve the shipping industry: Mina (port) Al-Shuwaikh located in Kuwait Bay and Mina Al-Shuaibah located just south of Al-Fahahil. Six other ports are presently active: Mina Al-Ahmadi, Mina Abdullah, Mina Al-Zour, Mina Dawhah and Ras Eisherej. These shipping facilities represent major modifications of the coastal zone. Along Kuwait's coast south of Kuwait Bay, Bishop (1999) estimated that 437 hectares of land have been reclaimed and that an additional 224 hectares have been dredged. The new Coast Guard Station at Al-Funtas reclaimed 1 km^2 of sea bottom and the proposed new Kuwait University marine laboratory campus adjacent to the Coast Guard Station will undoubtedly be responsible for additional reclamation.

Even with these modifications, Kuwait's coast remains a vital and productive component of the marine ecosystem. Many juvenile fish and crustacea require the shallow coastal waters to complete their life cycle, and in recognition of the importance of the shallow coastal waters, the Public Authority for Agriculture and Fisheries Resources (PAAFR) has banned commercial fishing within three nautical miles of the coast. Of major significance within this area is the presence of one of Kuwait's most important and vulnerable nursery habitats: the beds of benthic *Sargassum*. This brown alga grows in a discontinuous linear strip below the low tide mark and parallel to the coast where appropriate substrata exist. The benthic phase of *Sargassum* in Kuwait's waters is cyclical. Like *Ulva* and *Enteromorpha*, it grows best during the cooler months of late winter and early spring, reaching a peak in April. Rising water temperatures causes the *Sargassum* to break free of its holdfast and float to the surface. It is then either cast up on the beach as flotsam or carried out to open waters by either wind or tides. In its benthic phase, *Sargassum* is a primary nursery habitat for Kuwait's most important shrimp species, *P. semisulcatus*. Bishop et al. (1994) estimated as few as 50 hectares of benthic *Sargassum* along Kuwait's coast. Consequently, this habitat is extremely vulnerable to development and every measure should be taken to protect it.



FISHERIES Resources

Kuwait's dhows and speed boats used in commercial fishing (photo by Abdul-Rahman Abdul-Ghaffar).

Fisheries Resources

Finfish, Shrimp and Pearl Fisheries

Kuwait's sub-tropical fisheries are multispecies and multigear. Fishing operations are allowed throughout Kuwait's territorial waters year-around with the following exceptions. There are closed seasons for shrimp and zobaidy (*Pampus argenteus*), and commercial fishing is forbidden in Kuwait Bay and within three nautical miles of the coast. Recreational fishing with hook and line, however, is allowed within the restricted areas. Figures 105 and 106 display the fishing gears used in Kuwait's waters.

Kuwait's annual finfish and shrimp landings have varied around 5,883 and 2,200 tons, respectively. Finfish landings are enough to meet about 40 to 50% of the local demand, and the deficit is met by imports of fish from neighboring countries. In contrast, shrimp landings are able to meet local demand and support an export industry. The main commercial fish species belong to 14 families, with some being regionally distributed while others are considered to be local. Species such as zobaidy (*Pampus argenteus*), suboor (*Tenualosa ilisha*), and nagroor (*Pomadasys kaakan*) are shared with Iran and Iraq and migrate to Kuwait seasonally. Stocks of hamoor (*Epinephelus coioides*) and hamrah (*Lutjanus malabaricus*) are thought to be of a single unit throughout the northern Gulf, whereas stocks of newaiby (*Otolithes ruber*), shaem (*Acanthopagrus latus*) and maid (*Liza klunzingeri*) are considered to be local.

The complete checklist of Kuwait's ichthyofauna (Bishop, 2003) is presented in Table 6. The list includes 345 species belonging to 94 families.

Kuwait's fishing fleet is divided into two main sectors, the artisanal fleet and the industrial fleet. The artisanal fleet is comprised of 120 wooden dhow boats and 748



Fish by- catch accounts for the largest percentage of the catch by shrimp trawls (photo by Dr. James Bishop).



Fishermen often clear their gill nets of the catch (mullet in this case) back at the harbor (photo by Abdul-Rahman Abdul-Ghaffar).

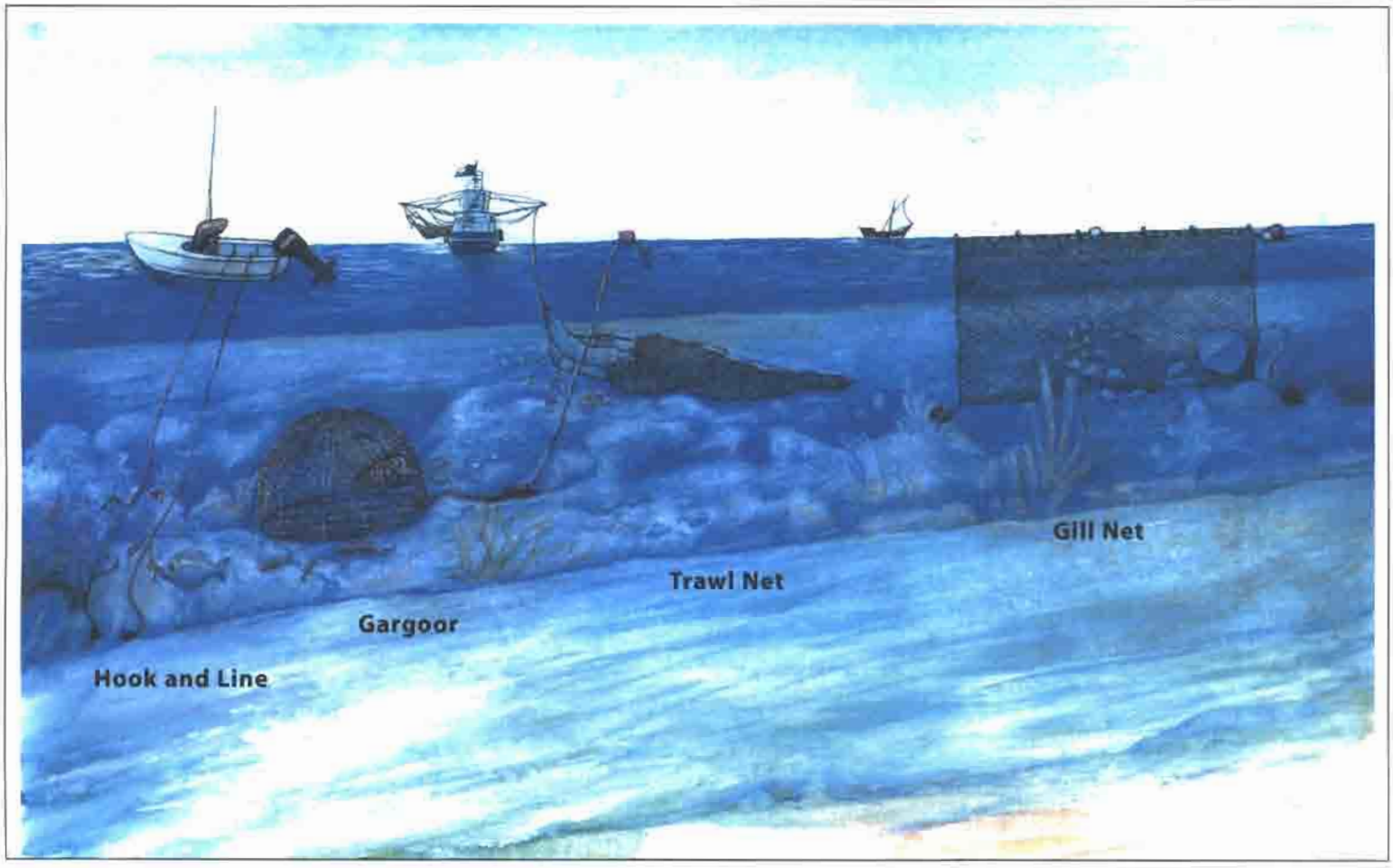


Fig. 105. The different types of fishing gear used in Kuwait: hook and line, gargoor, trawl net and gill net (drawing by Samia Omar).

fiberglass speedboats (fitted with outboard engines of 200 hp and range in size from to 6.5 to 7 m). Specifications of wooden boats are as follows: average length 19 m (range 14-23 m), beam 5.7 m (range 3.7-6.6 m), draft 2.4 m (range 1.8-3 m), engine power 250 hp (range 132-365 hp), and gross tonnage 45 t (range 13-95 t). Each boat is licensed to use only one gear type of drift gill nets, gill nets, gargoor, or shrimp trawl net. The actual number of operating boats varies according to the season and is usually less than the number of licensed boats. The artisanal fleet lands about 90% of the finfish and 44% of the shrimp, with the remainder being landed by the industrial fleet.

The artisanal fleet employs shrimp trawls (only 33 dhow boats are licensed), drift gill nets and gargoor fish traps. Catches are landed at the Sief Harbor (Al-Sharq; 29°23'04"N 47°58'42"E), Al-Saqer (known also as Al-Kherafi) Harbor (29°22'21"N 47°57'51"E) and Fahahil Harbor (29°04'48"N 48°08'30"E).

Gill nets (Fig. 105) may be stationary or drift with the current. These nets are made from monofilament nylon with pieces of polystyrene or rubber floats. These nets entangle the fishes' operculum (gill cover) or the area directly behind the operculum. Generally, gill nets are highly selective because they catch fish within a specific size range; fish larger than the mesh size are not entangled and those smaller pass right through. Stationary gill nets are used to catch maid and beyah (*Liza* species), but they are usually smaller in mesh size than drift gill nets. Drift gill nets are set to hang vertically in the water column from a series of floats attached to their upper edge and weights are attached to their lower edge. The nets can be set to catch open water species, such as zobaidy, suboor, khobat (*Scomberomorus guttatus*) and chanaed (*Scomberomorus commerson*), or set to catch demersal species, such as nagroor, shaem and newaiby. These nets vary in mesh size (45-152 mm) according to the target species. Total length of single nets ranges from 36 to 58 m (and can reach 100 m), with heights of 2.4 to 3.2 m (occasionally up to 10 m). Usually, about 20 to 40 of these single nets are attached in a series and deployed for each haul by the speedboat; even longer nets are deployed by the dhow boats.

Traditionally, hemispherical wire traps, known as gargoor (Fig. 105), have been employed to capture bottom-dwelling fish. These traps are constructed of galvanized wire and vary in diameter from 1 to 2.6 m, with mesh sizes ranging from 20 to 50 mm. One funnel is placed on the side near the bottom for fish entry, and a hatch allows the trap to be

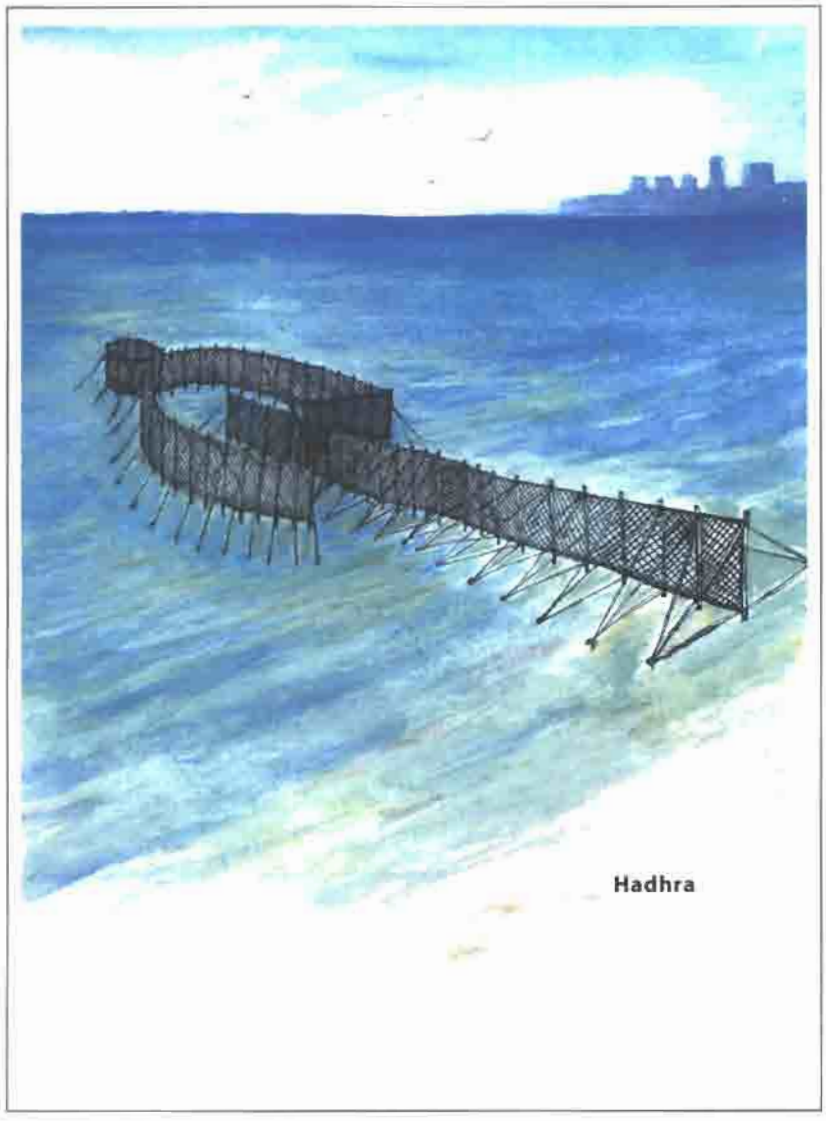


Fig. 106. A diagram showing the hadhra (drawing by Samia Omar).

baited (usually with oily or minced fish) and the catch to be removed. Gargoor are deployed singly or in sets of 4-5 traps in rocky areas or with coral outcrops in depths of 10 to 35 m. Each dhow boat can deploy and pull as many as 300 traps per trip of three to five days, whereas speedboats can pull a maximum of 50 gargoor daily. The main demersal species caught by gargoor are considered to be high value fishes, and include hamoor, shaem, hamrah, fersh (*Plectorhinchus pictus*), newaiby and sheiry (*Lethrinus* species).

Hadhras, or stake traps, are another traditional fishing gear, but do not involve the artisanal fleet. Hadhra (Fig. 106) is constructed in the intertidal zone to catch fish that follow the tide as it rises and falls. In 2002, the number of licensed hadhras in Kuwait was 522, but the actual number in operation is unknown. A hadhra consists of three main components: 1) a fence 50 to 70 m in length; 2) a heart-shaped entrapment area about 24 m in diameter; and 3) a smaller terminal heart-shape catchment area. Hadhras are constructed perpendicularly to the shoreline, with the fence running from the beach into the entrapment area, which is constructed just below the low tide mark. The wire fencing ranges from 19 to 36 mm mesh size and is supported by bamboo poles spaced 1.3 to 1.5 m apart. The fence intercepts the fish as they swim parallel to shore and directs them into the entrapment area, and eventually into the catchment area with the falling tide. The catchment area is cleared of fish during the low



Hadhra in Kuwait's waters (photo by Abdul-Rahman Abdul-Ghaffar).



Gargoor traps (photo by Abdul-Rahman Abdul-Ghaffar).

tide. Hadhras capture a variety of small fish species, small sharks, rays, crabs and, occasionally, shrimp and turtles. Fish species include sardines, anchovies, maid, dhelah (*Scomberoides commersonnianus* and *S. lysan*), shaem, nagroor and suboor.

Both dhow boats and industrial shrimp trawlers use demersal trawl nets (Fig. 105) to target shrimp. The trawl nets consist of a conical or funnel-shaped net leading the shrimp (and fish) into a bag or a cod-end in which the catch is retained. The dhow boats pull one trawl net while the industrial boats pull a pair, one on each side of the vessel. Tickler chains along the footrope of the nets cause buried shrimp to jump from the bottom into the net mouth while floats along the headline help keep the net mouth open.

The industrial shrimp fleet is comprised of 35 steel-hulled Gulf-of-Mexico type trawlers with the following specifications: average length 20 to 32 m, beam 3.7 to 7.3 m, draft 2.4 to 3.5 m, tonnage 79 to 159 t, and engine size 270 to 565 hp. Ninety percent of the landings are shrimp, which are unloaded at either Dawhah Port (29°22'48"N 47°48'00"E) or Shuaiba Port (29°02"18"N 48°09'36"E). The shrimping season usually starts 1st of September when the shrimp size is optimal for economic returns. Season closure can vary from 15 January to 15 March or later, depending on spawning biomass, which is estimated from catch rates.

The principal shrimp species is *Penaeus semisulcatus*, which comprises from 50% to > 90% of the landings of both fleets, depending on the year. The second important species is *Metapenaeus affinis*. Other species found in the catches in minor quantities are *Parapenaeopsis stylifera* and *Metapenaeus stebbingi*. There are 11 shrimp species that are reported from Kuwait's waters (Table 7). About 50% of the industrial catches are landed, and with the dhows' catches, are placed on ice to be sold for local consumption. The remainder is packed and frozen by the two processing plants owned by the companies for export purposes.

The life span of shrimp species in Kuwait's fishery is about one year, and year-to-year catch variation has ranged from 1000 t in 1975/76 to > 5000 t in 1988/89. It is believed that both fishing effort and environmental factors play important roles in determining the success of annual recruitment, and hence, the annual catches. Optimization of the landings in the 1988/89 season was mainly due to a reduction in fishing pressure and low spring temperatures and salinity (increase in Shatt Al-Arab flow rates). As a result, the recruitment increased to the highest levels recorded during the previous fifteen



Fish culture cages in Kuwait Bay (photo by Dr. Salam Al-Ablani).

years in this fishery. The post-invasion catches indicate that the recruitment level was about 50% lower than that of the pre-invasion period because the fishing effort was higher than the recommended level, and also because of lower flows of Shatt Al-Arab River.

The pearl fishery was an important industry long before the discovery of oil, and dominated Kuwait's economy from the 1800s to the early 1900s (artificial pearl industry started in the 1930s). Until recently, the fishery consisted of about 25 speedboats, each with a single diver using hookah air supply system (a system that pumps air to the diver via a length of air hose). Eleven major pearl oyster beds are known and are located in Kuwait's southern waters. The beds vary in size from one to several square kilometers at 10-20 m deep starting from Mina Al-Shauiba to the southern borders with Saudi Arabia. The estimated landings of oysters in 1989 was 287 t with a market value of US $ 1.0 million. The major species harvested for pearling is the Rayed Pearl Oyster, *Pinctada radiata*, and rarely the Black-lip Pearl Oyster *Pinctada margritifera*. The wing oyster *Pteria penguin* used to beharvested for mother-of-pearl.

Aquaculture

Aquaculture production in Kuwait has been expanding while the catches from the wild have been declining. Currently, local finfish landings (4500 - 7000 t) in Kuwait meet only 40 to 50 % of national demand, and Kuwait is a net importer of fish and fisheries products. Aquaculture offers the prospect of increasing supplies of fresh fish that the traditional capture fisheries are unable to meet.

Brackish water aquaculture for typically freshwater Tilapia started in 1997 as an integrated component of cultivated crops in Al-Wafrah and Al-Abdali farms. The estimated total annual fish production is about 25 t.

Marine aquaculture activities in Kuwait are exclusively carried out by one company, which was established in 1986. The grow-out production system is composed of 74 floating marine sea cages, enclosing an area of 13,966 m^2 (1.4 ha), and located off Dawhah in the western part of Kuwait Bay. The company's actual fish production started in 1992, with 160 t targeted for that year. The 1996 target was 600 t/yr. The main species are gilthead sea bream (*Sparus aurata* [*auratus*]), sobaity (*Sparidentex hasta*), hamoor (*Epinephelus coioides*), and shaem (*Acanthopagrus latus*). No hatchery or fish food production facilities are available within the company, and therefore, the sea bream fingerlings are imported from Greece, Cyprus, and Italy, while sobaity are imported from Bahrain or are supplied by the Kuwait Institute for Scientific Research.

Another company was established in the year 2000 explicitly for producing fry in the Arabian Gulf region. The hatchery is located within the Mariculture and Fisheries Department of the Kuwait Institute for Scientific Research. The cultured species are sobaity, shaem, hamoor, European seabass (*Dicentrarchus labrax*), and gilthead sea bream. Although the principal targeted markets are the United Arab Emirates and Oman, shaem fry are also sold to few Kuwait farms using brackish water.



Mullet catch in gill net (photo by Abdul-Rahman Abdul-Ghaffar).

Major Capture Species

Kuwait's zobaidy, *Pampus argenteus*, stock is shared among the countries of the northern Arabian Gulf (Kuwait, Iraq and Iran). This single species accounts for about 30 to 40% of the total value of Kuwait's finfish fishery. Since 1995, the catches have decreased from about 1100 t to 130 t in 2001. Zobaidy migrate seasonally between major spawning grounds in estuaries near to river mouths in Iran and Iraq, and feeding areas in Kuwait's and Iran's waters. Its distribution in Kuwait is restricted to the more northern waters of Kuwait Bay, around Failaka and Bubiyan Islands, and areas south and southeast of Bubyian Island (Fig. 107). The primary nursery grounds are believed to be in Iran's waters as well as adjacent waters in Iraq. The closed fishing season for zobaidy in Kuwait is from June to August.

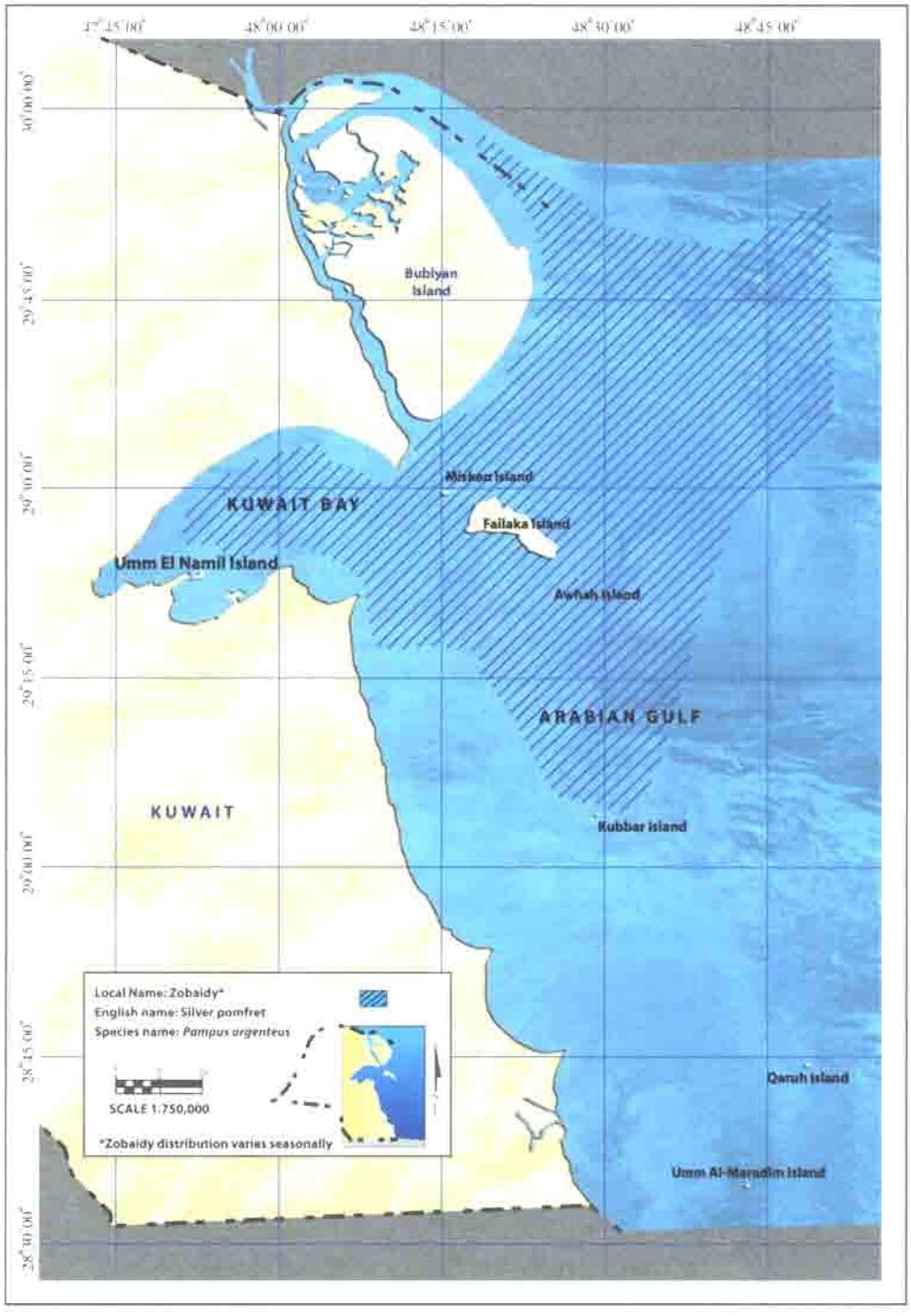
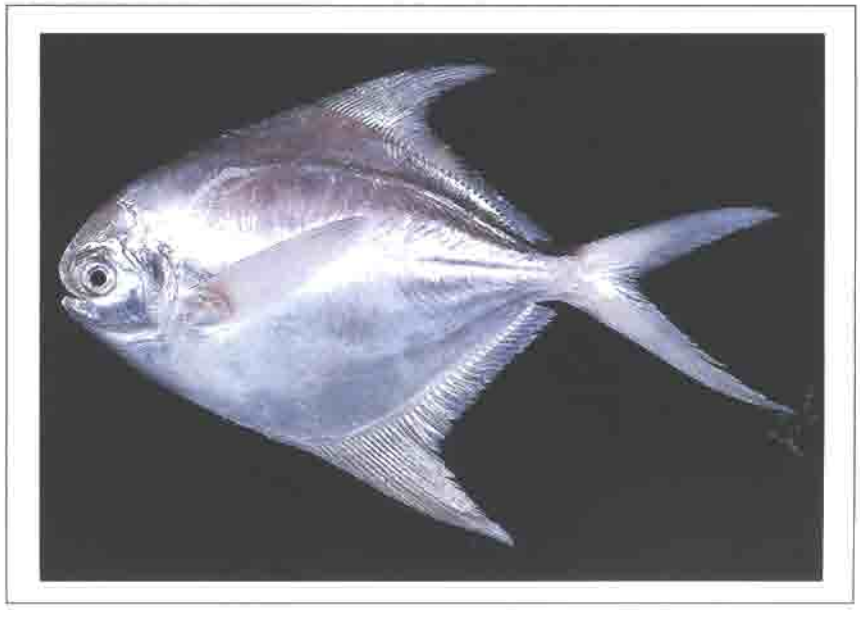


Fig. 107. The spatial distribution of zobaidy (silver pomfret) in Kuwait's waters.



Zobaidy

Suboor, *Tenualosa ilisha*, is an anadromous species that moves from salt water to fresh water to complete its life cycle. Like zobaidy, suboor is shared among the countries of the northern Arabian Gulf. This species migrates to marshes and rivers in Iraq and Iran to spawn. The juveniles and recruits move down river to the Gulf. Suboor landings in Kuwait's waters have averaged around 1,000 t in the last six years. The distribution of suboor in Kuwait's waters extends from Kuwait Bay, around Bubyian and Warbah Islands (including Khor Al-Sabbyiah and Khor Abdullah) to areas south and southeast to Bubyian Island (Fig. 108).

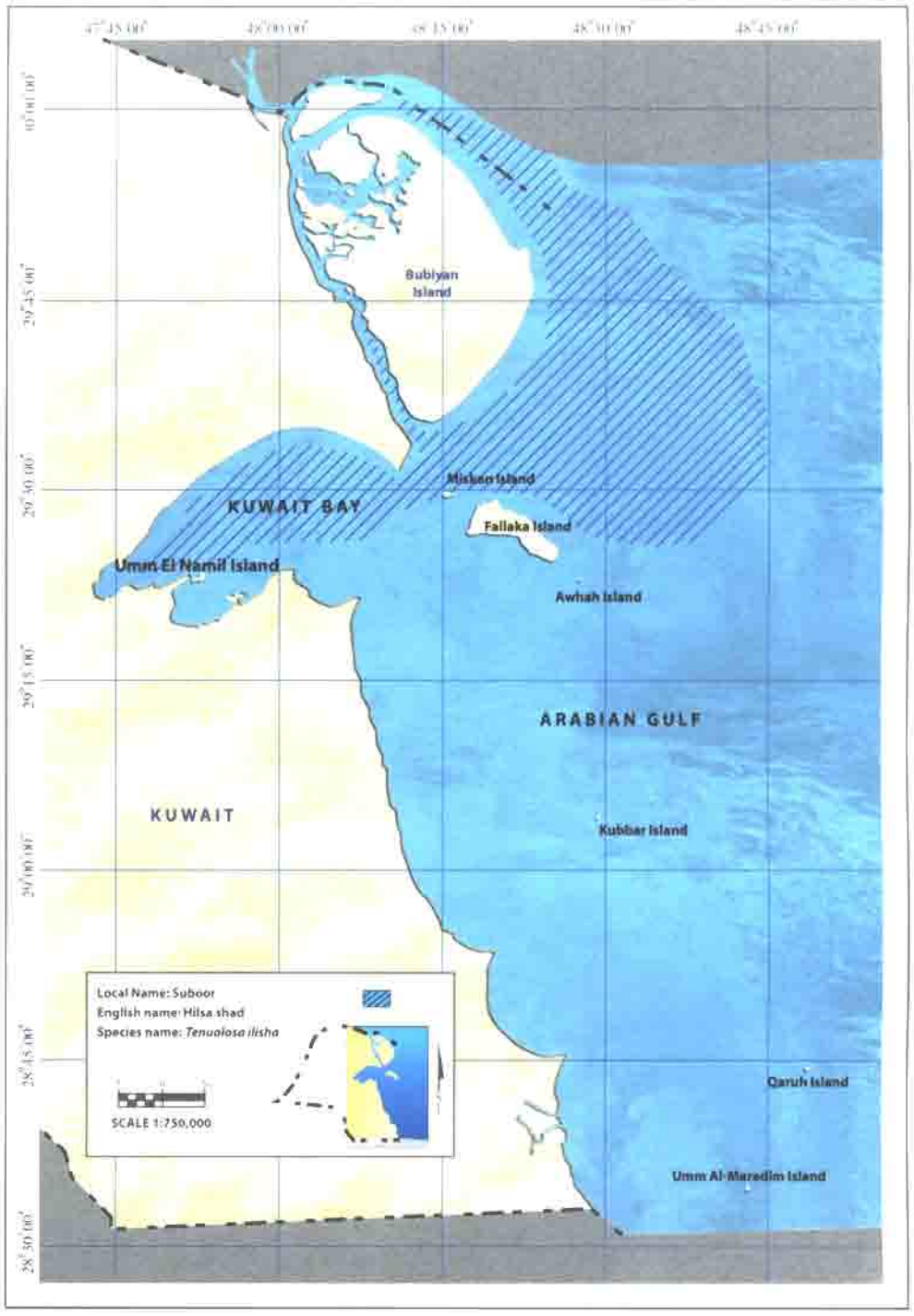


Fig. 108. The spatial distribution of suboor (Hilsa shad) in Kuwait's waters.



Suboor

Newaiby, *Otolithes ruber* and shaem, *Acanthopagrus latus*, are demersal species whose stocks are considered to be local. Both species spawn in Kuwait's waters, and juveniles are believed to remain in Kuwait's coastal waters as they mature. Newaiby and shaem are distributed throughout Kuwait's territorial waters (Figs. 109 and 110), and different fishing gears capture both species. From 1996 through 2001, the annual landings averaged about 1,034 t for newaiby and about 282 t for shaem.

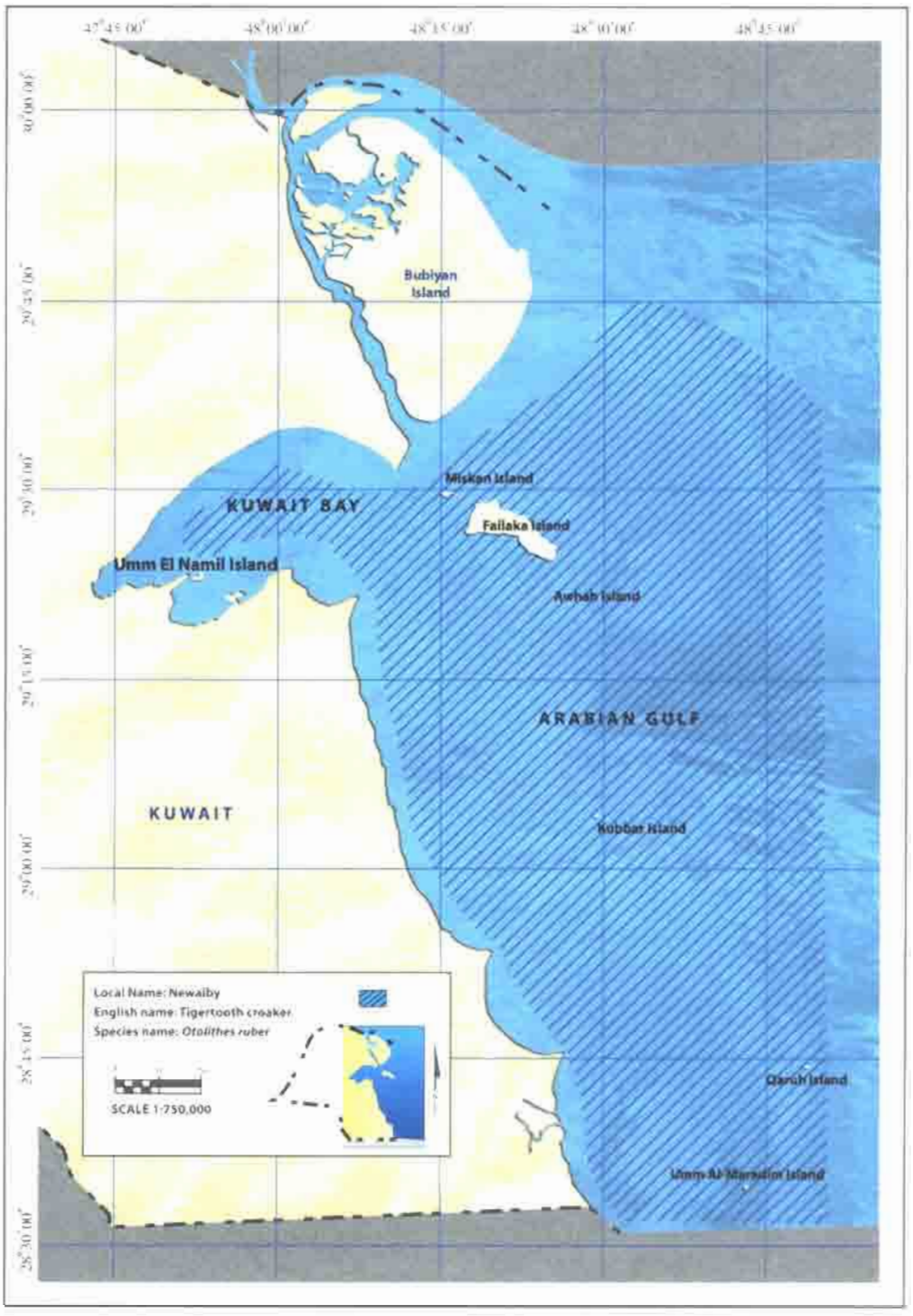
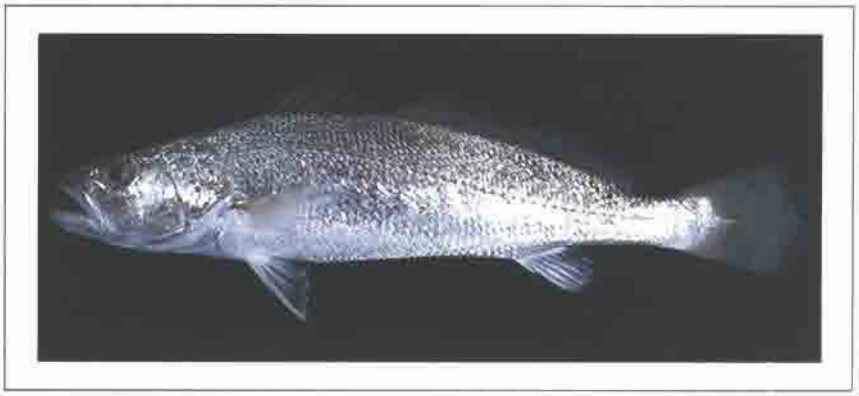


Fig. 109. The spatial distribution of newaiby (tigertooth croaker) in Kuwait's waters.



Newaiby

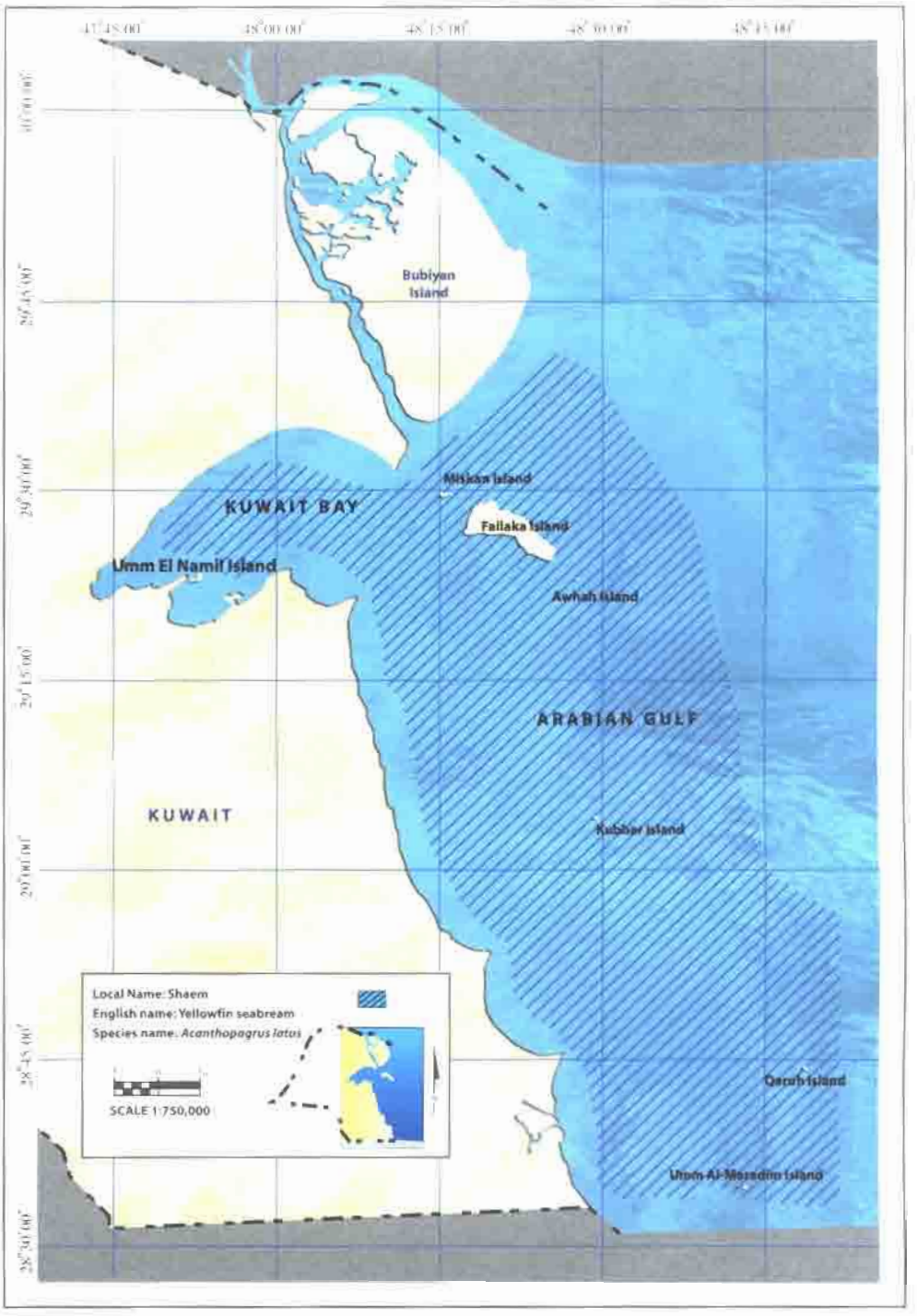


Fig. 110. The spatial distribution of shaem (yellowfin seabream) in Kuwait's waters.



Shaem

The other important demersal species, which inhabit waters from 5 to 30 m, are hamoor, *Epinephelus coioides*, nagroor, *Pomadasys kakaan*, hamrah, *Lutjanus malabaricus*, fersh, *Plectorhinchus pictus*, and sheiry, *Lethrinus nebulosus*. Hamoor are found in deeper areas of Kuwait Bay and throughout the rest of Kuwait's waters (Fig. 111), whereas hamrah and fersh are more commonly captured in Kuwait's more southern waters from Kubbar Island to Saudi Arabia (Figs. 112 and 113).

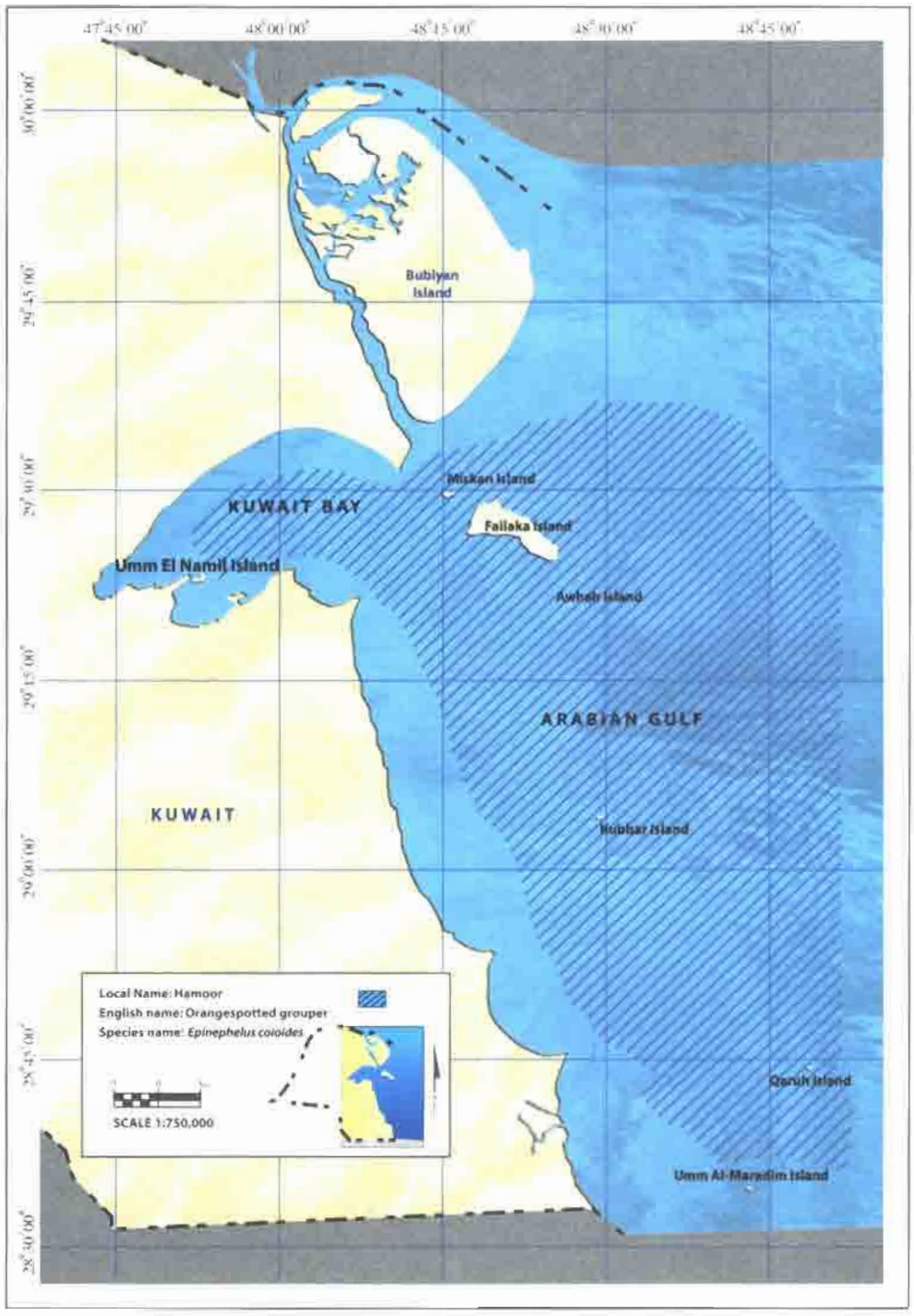
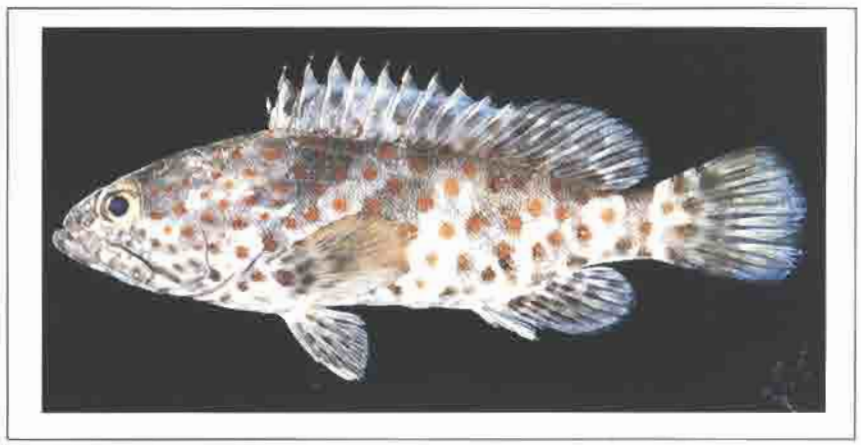


Fig. 111. The spatial distribution of hamoor (orange-spotted grouper) in Kuwait's waters.



Hamoor

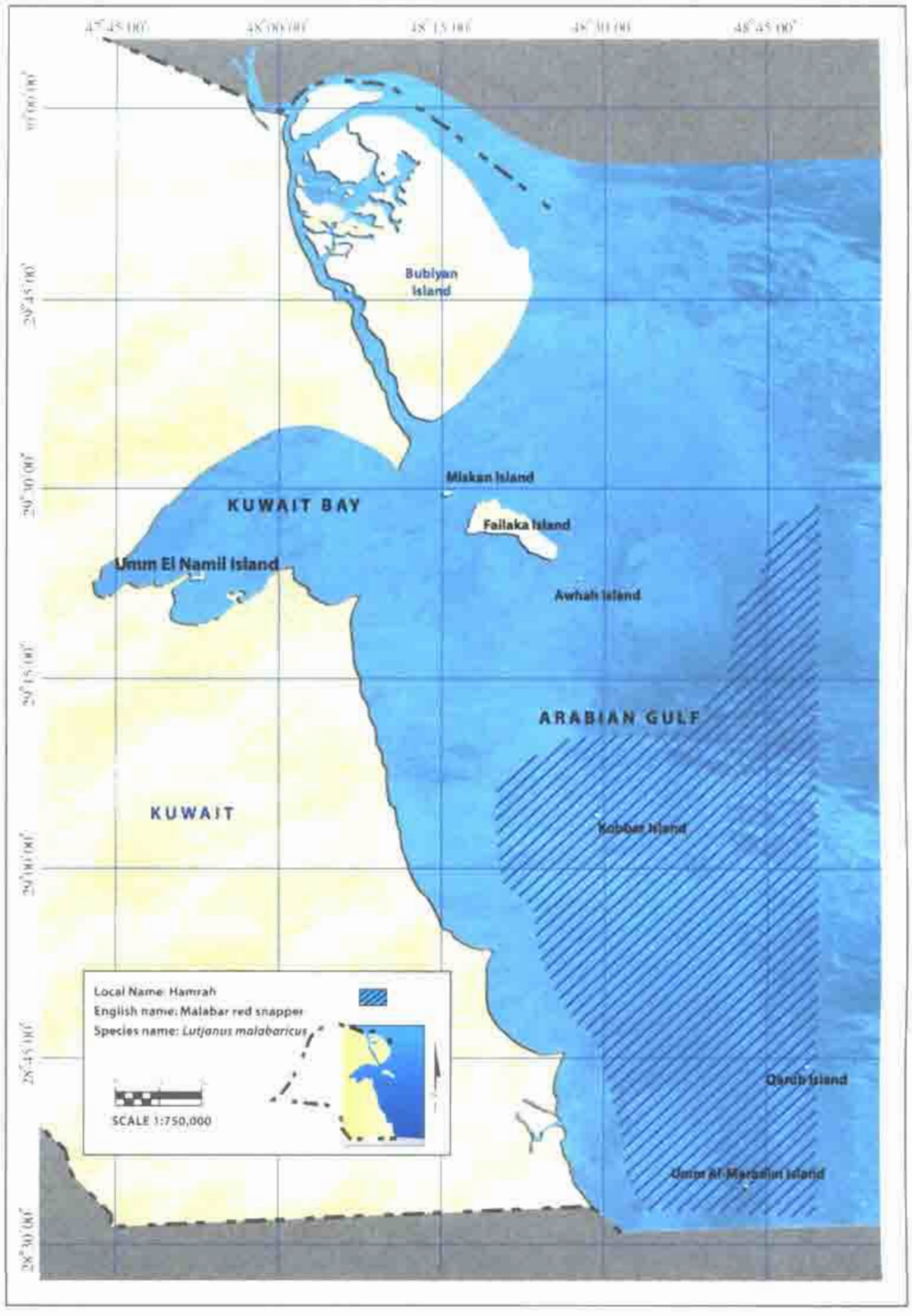


Fig. 112. The spatial distribution of hamrah (Malabar red snapper) in Kuwait's waters.



Hamrah

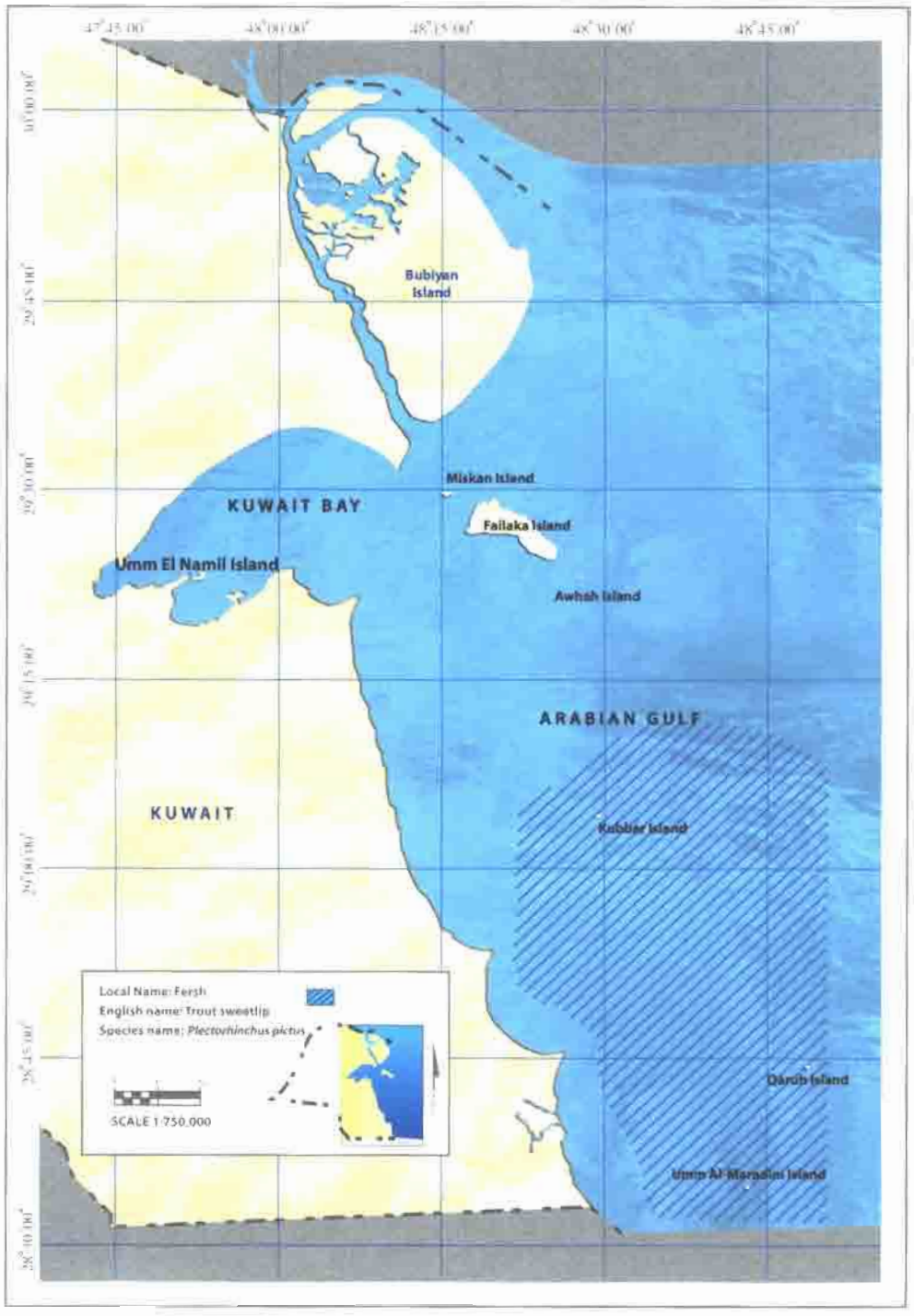


Fig. 113. The spatial distribution of fersh (trout sweetlip) in Kuwait's waters.



Fersh

Fishing areas for nagroor are restricted only to the eastern sea area from Awhah Island to Kubbar Island during March to June (Fig. 114).

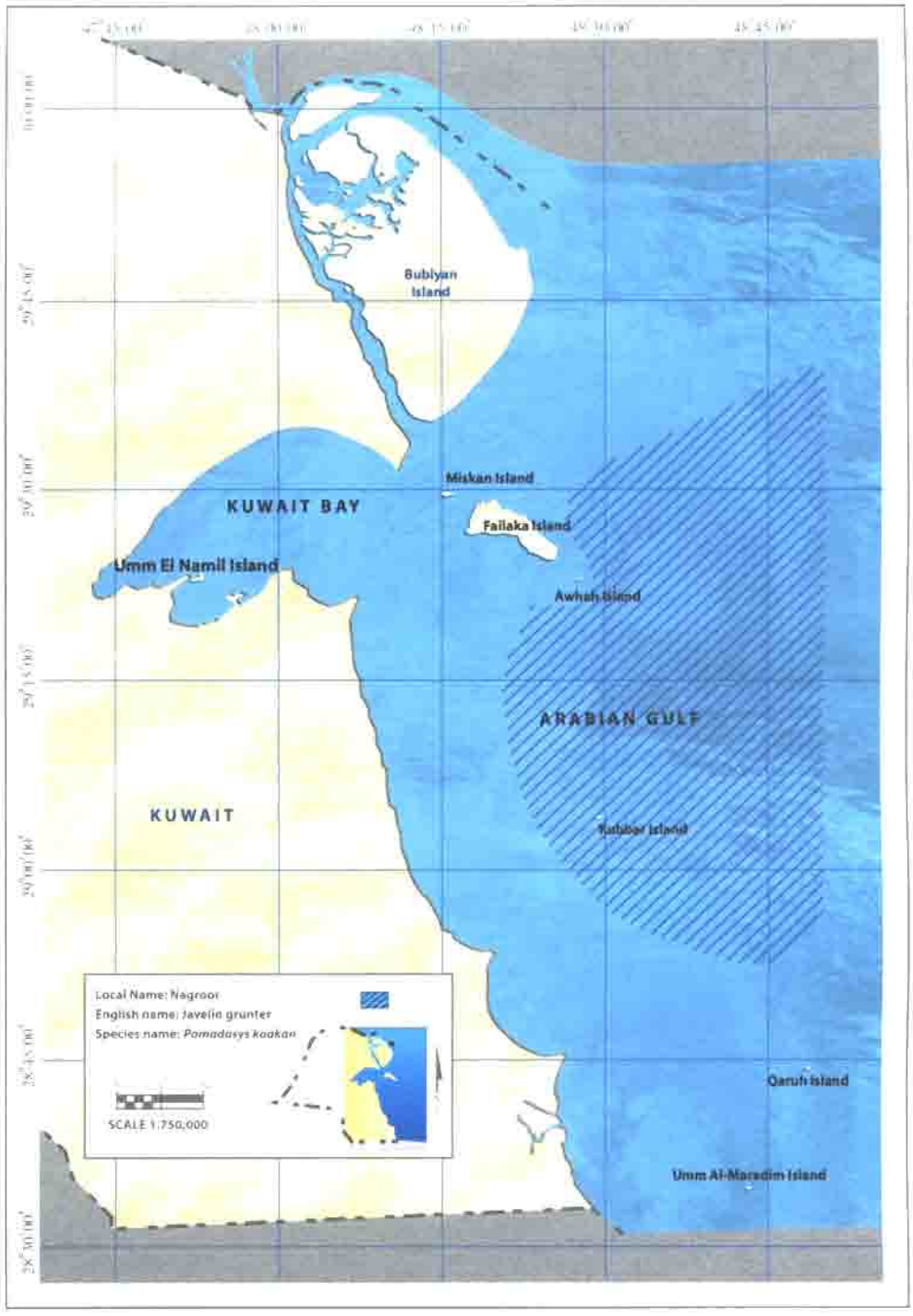
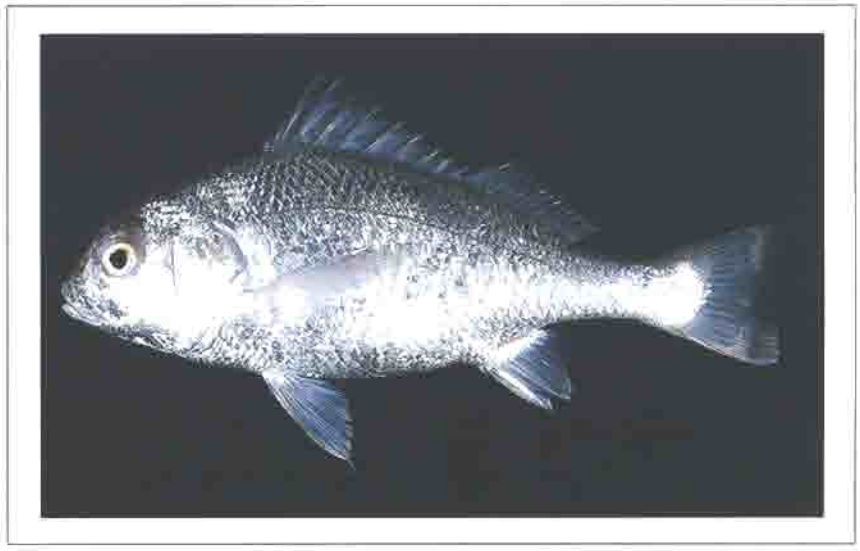


Fig. 114. The spatial distribution of nagroor (Javelin grunter) in Kuwait's waters.



Nagroor

Sheiry distribution is confined to the more southern waters, especially around Qaruh and Umm Al-Maradim Islands (Fig. 115); however, the juveniles of this species have been found recently in Kuwait Bay.

Annual landings average as follows: 251 t for hamoor, 57 t for hamrah, 162 t for nagroor, 40 t for sheiry and 57 t for fersh.

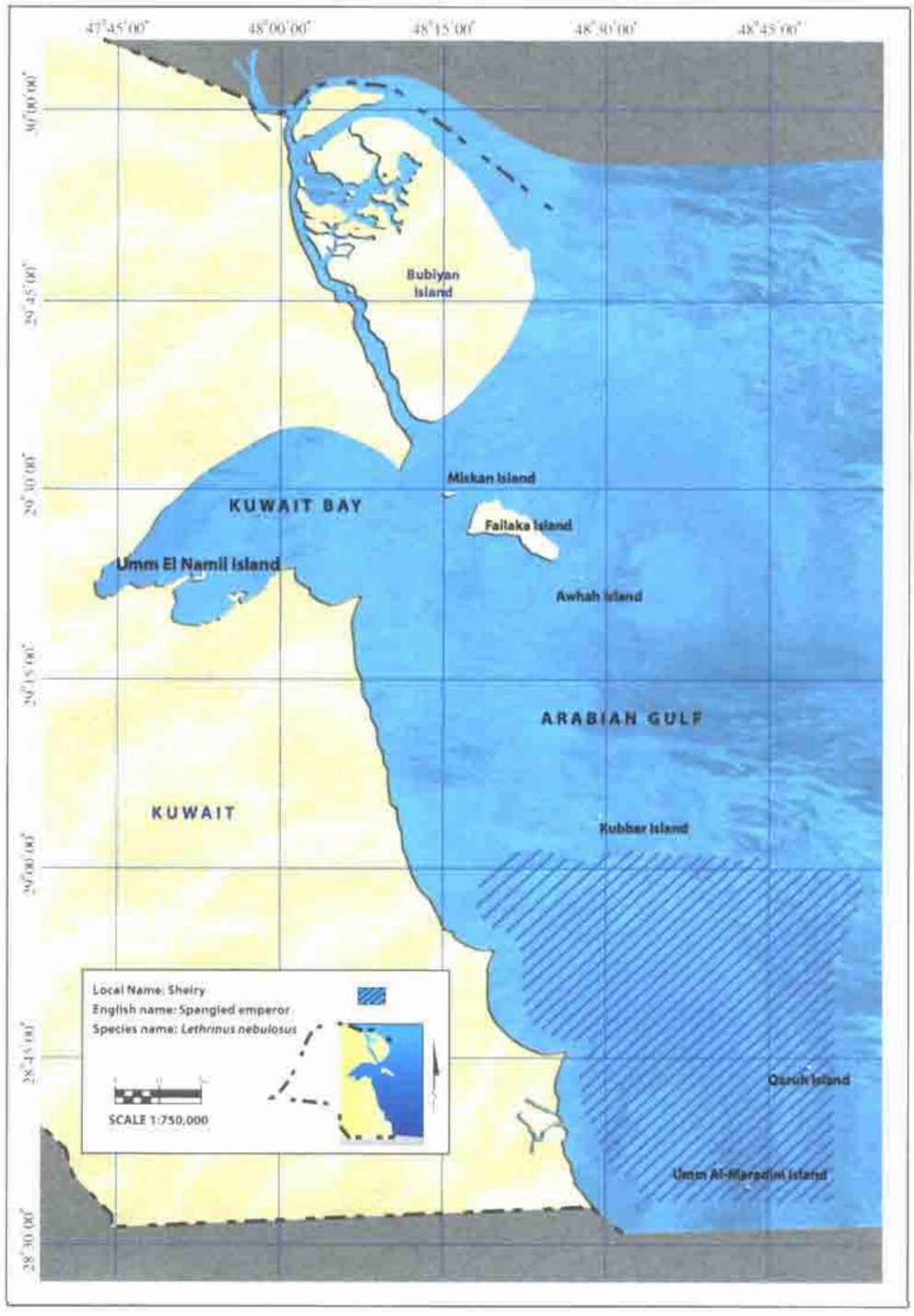


Fig. 115. The spatial distribution of sheiry (spangled emperor) in Kuwait's waters.



Sheiry

Distribution of bassi (*Nemipterus peronii*) in Kuwait's waters (Fig. 116) is similar to that of sheiry (Fig. 115).

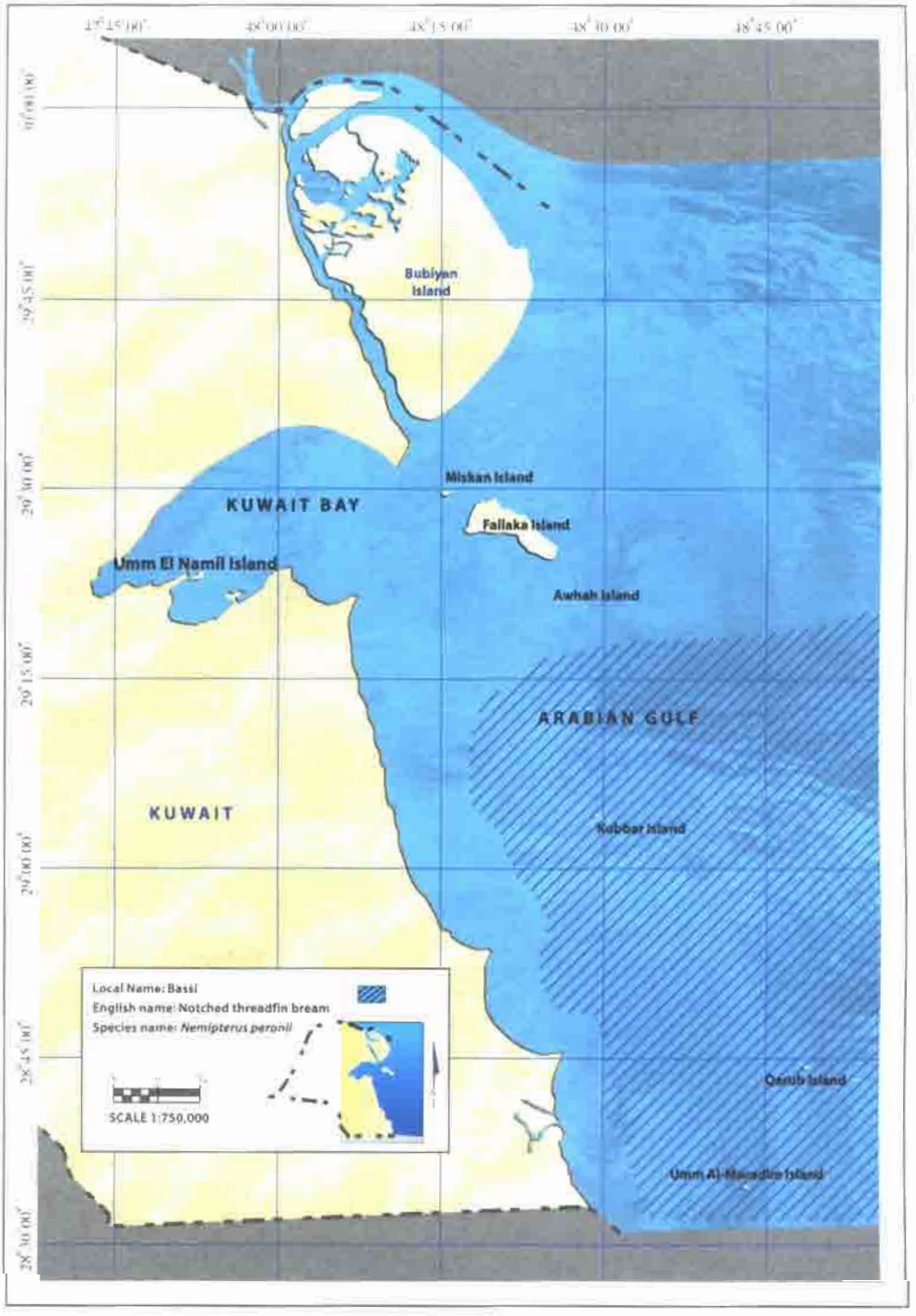
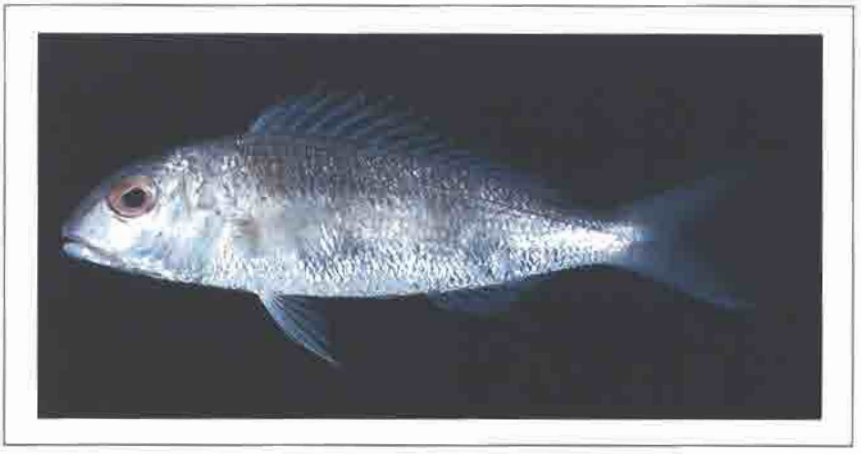


Fig. 116. The spatial distribution of bassi (notched threadfin bream) in Kuwait's waters.



Bassi

Maid, *Liza klunzingeri*, and beyah, *Liza subviridis*, are the most important small pelagic species for the gill net fishery. Annual landings from 1996 through 2001 averaged 686 t for maid and 53 t for beyah. Maid and beyah distribution is restricted to Kuwait's northern waters, including Kuwait Bay, all areas around Failaka Island and Bubyian Island (Figs. 117 and 118).

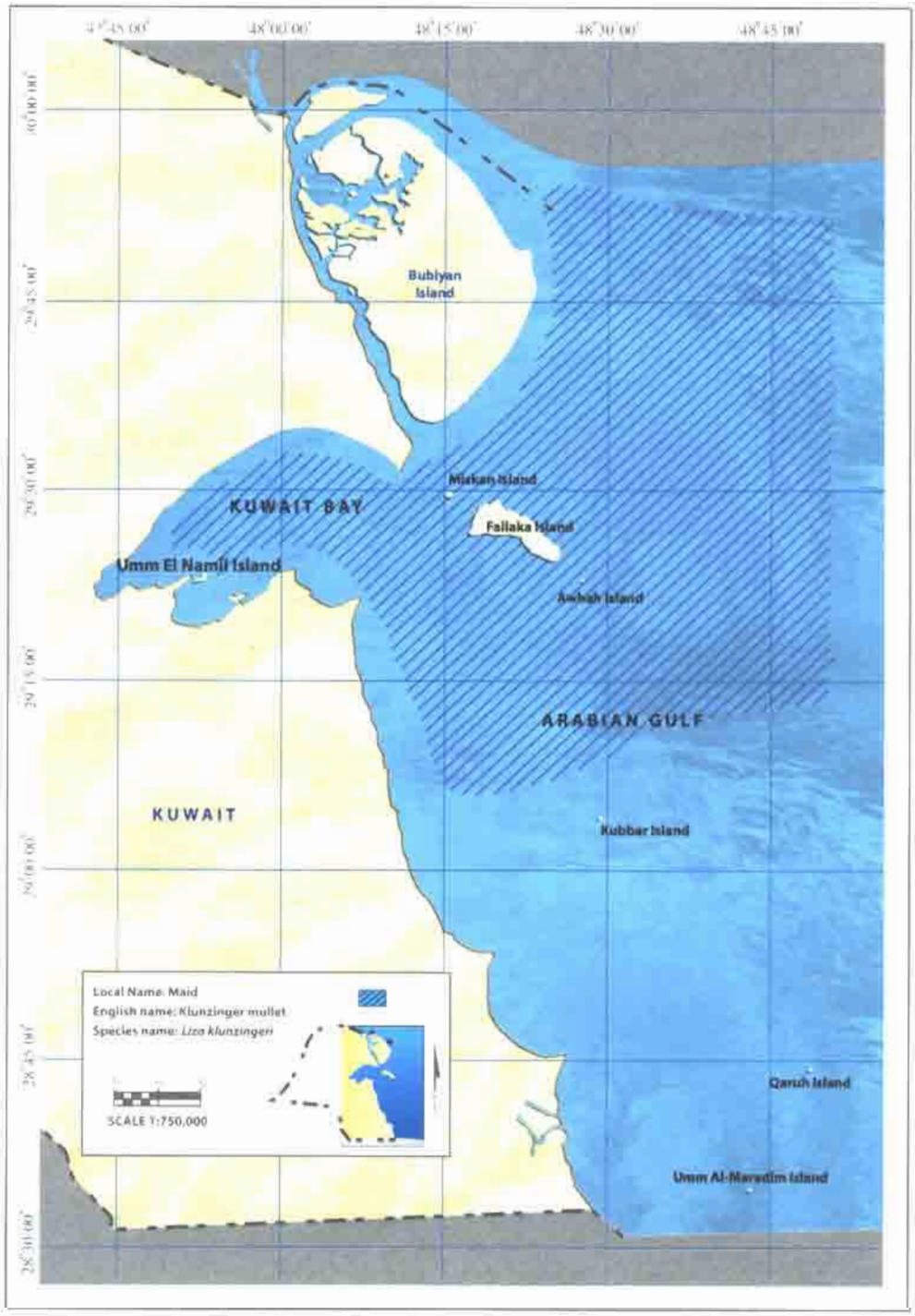


Fig. 117. The spatial distribution of maid (Klunzinger mullet) in Kuwait's waters.



Maid

Photo by Abdul-Rahman Abdul-Ghaffar

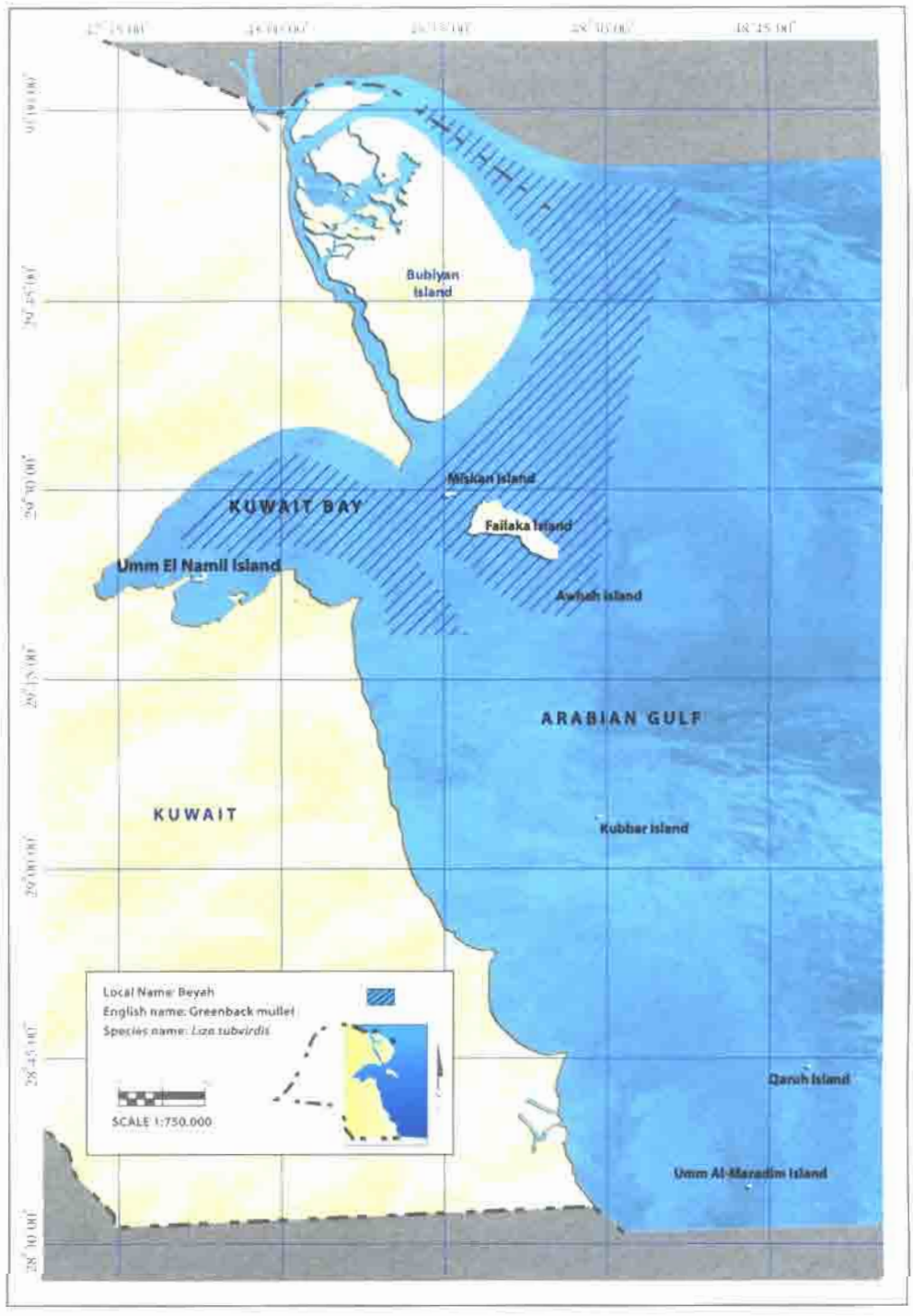


Fig. 118. The spatial distribution of beyah (Greenback mullet) in Kuwait's waters.



Beyah

Chim (sea catfish), involving four species and of little culinary importance, are distributed throughout Kuwait's waters (Fig. 119).

The principal shrimp species is *Penaeus semisulcatus*, which contributes about 50 to 60%, or more, to the landings of both fishing fleets (artisanal and industrial). This shrimp species is distributed in Kuwait Bay, and in almost all Kuwait's waters south of Bubiyan Island. The main nursery areas for this species are Kuwait Bay and shallow areas near the coast from Ras Al-Ardh to the southern border with Saudi Arabia. The second important species is *Metapenaeus affinis*, which is captured with a third species, *Parapenaeopsis stylifera*. The distribution and fishing grounds of the latter two species are restricted to areas around Failaka Island to areas north of Kubbar Island. The nursery habitat consists of extensive mudflats of Kuwait Bay and around Bubiyan Island. About 50% of the industrial catches and the entire dhow catches are landed fresh for local consumption. The remainder is packed and frozen for export by Kuwait's two industrial fishing companies, the United Fisheries of Kuwait and the National Fishing Company.

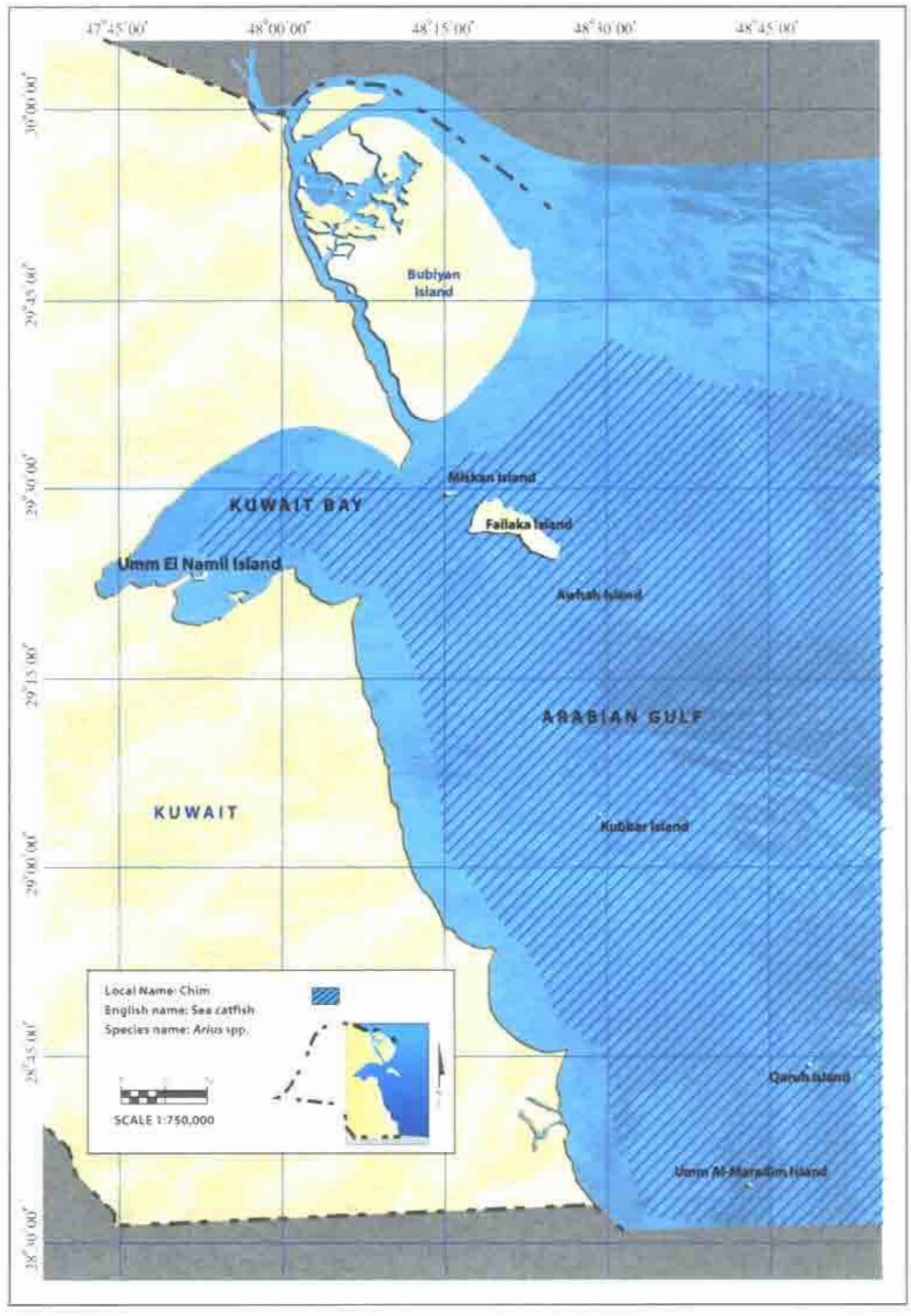
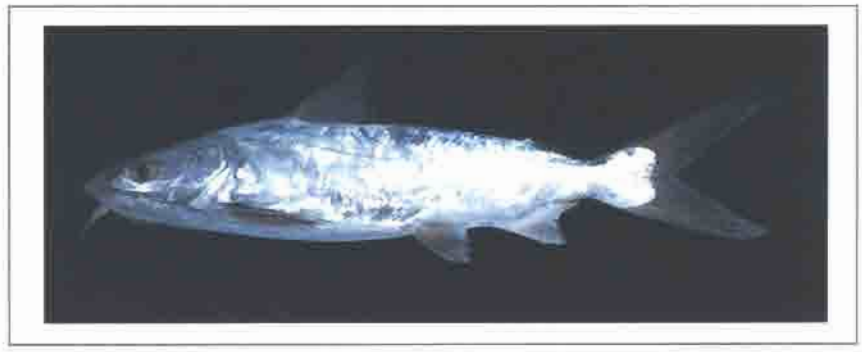


Fig. 119. The spatial distribution of chim (sea catfish) in Kuwait's waters.



Chim

Table 6. Biodiversity List of Fish Species Reported in Kuwait's Waters (Source: Bishop, 2003).

Order	Family	Genus and species	English name
Orectolobiformes	Hemiscylliidae	*Chiloscyllium arabicum*	Arabian Carpetshark
		Chiloscyllium griseum	Grey Bambooshark
	Ginglymostomatidae	*Nebrius ferrugineus*	Tawny Nurse Shark
	Rhincodontidae	*Rhincodon typus*	Whale Shark
	Stegostomatidae	*Stegostoma fasciatum*	Zebra Shark
Carcharhiniformes	Triakidae	*Mustelus mosis*	Arabian Smoothhound
	Hemigaleidae	*Chaenogaleus macrostoma*	Hooktooth Shark
		Paragaleus randalli	Slender Weasel Shark
	Carcharhinidae	*Carcharhinus albimarginatus*	Silvertip Shark
		Carcharhinus brevipinna	Spinner Shark
		Carcharhinus dussumieri	Whitecheek Shark
		Charcharhinus falciformis	Silky Shark
		Carcharhinus leucas	Bull Shark
		Carcharhinus limbatus	Blacktip Shark
		Carcharhinus melanopterus	Blacktip Reef Shark
		Carcharhinus plumbeus	Sandbar Shark
		Carcharhinus sorrah	Spot-tail Shark
		Galeocerdo cuveri	Tiger Shark
		Rhizoprionodon acutus	Milk Shark
		Rhizoprionodon oligolinx	Grey Sharpnose Shark
		Scoliodon laticaudus	Spadenose Shark
		Sphyrna mokarran	Great Hammerhead
		Carcharias taurus	Sand Tiger Shark
		Pristis zijsron	Green Sawfish
		Torpedo panthera	Panther Electric Ray
		Torpedo sinuspersici	Marbled Electric Ray
		Rhina ancylostoma	Bowmouth Guitarfish
		Rhinobatos granulatus	Sharpnose Guitarfish
		Rhynchobatus djiddensis	Giant Guitarfish
		Himantura bleekeri	Bleeker's Whipray
		Himantura gerrardi	Sharpnose Stingray
		Himantura imbricata	Scaly Whipray
		Himantura uarnak	Honeycomb Whipray
		Himantura walga	Dwarf Whipray
		Himantura sp.	Whipray
		Pastinachus sephen	Cowtail Stingray
		Taeniura meyeni	Blotched Fantail Ray
	Gymnuridae	*Gymnura poecilura*	Longtail Butterfly Ray
	Myliobatidae	*Aetobatus narinari*	Spotted Eagle Ray
		Aetomylaeus maculatus	Mottled Eagle Ray
		Aetomylaeus nichofii	Banded Eagle Ray
		Aetomylaeus sp.	Eagle ray
		Rhinoptera javanica	Javanese Cownose Ray
Elopiformes	Megalopidae	*Megalops cyprinoides*	Indo-Pacific Tarpon

Order	Family	Genus and species	English name
Anguilliformes	Muraenidae		Starry Moray
		Gymnomuraena zebra	Zebra Moray
		Gymnothorax undulatus	Undulated Moray
	Muraenesocidae	*Muraenesox cinereus*	Daggertooth Pike Conger
Clupeiformes	Clupeidae	*Anodontostoma chacunda*	Chacunda Gizzard Shad
		Dussumieria acuta	Rainbow Sardine
		Herklotsichthys lossei	Gulf Herring
		Herklotsichthys quadrimaculatus	Bluestripe Herring
		Hilsa kelee	Kelee Shad
		Nematalosa nasus	Bloch's Gizzard Shad
		Opisthopterus valenciennesi	Slender Tardoor
		Sardinella albella	White Sardinella
		Sardinella fimbriata	Fingerscale Sardinella
		Sardinella gibbosa	Goldstripe Sardinella
		Sardinella longiceps	Indian Oil Sardinella
		Sardinella melanura	Blacktip Sardinella
		Sardinella sindensis	Sind Sardinella
		Tenualosa ilisha	Hilsha Shad
	Pristigasteridae	*Ilisha compressa*	Compressed Ilisha
		Ilisha melastoma	Indian Ilisha
		Ilisha sirishai	Lobejaw Ilisha
	Engraulidae	*Encrasicholina devisi*	Devis' Anchovy
		Encrasicholina punctifer	Bucaneer Anchovy
		Stolephorus indicus	Indian Anchovy
		Thryssa dussumieri	Dussumier's Thryssa
		Thryssa hamiltonii	Hamilton's Thryssa
		Thryssa vitrirostris	Orangemouth Anchovy
		Thryssa whiteheadi	Whitehead's Thryssa
	Chirocentridae	*Chirocentrus dorab*	Dorab Wolf-Herring
		Chirocentrus nudus	Whitefin Wolf-Herring
	Chanidae	*Chanos chanos*	Milkfish
Siluriformes	Ariidae	*Arius bilineatus*	Roundsnout Sea Catfish
		Arius dussumieri	Blacktip Sea Catfish
		Arius tenuispinis	Thinspine Sea Catfish
		Arius thalassinus	Giant Sea Catfish
	Plotosidae	*Plotosus lineatus*	Striped Eel Catfish
Aulopiformes	Synodontidae	*Saurida tumbil*	Greater Lizardfish
		Saurida undosquamis	Brushtooth Lizardfish
		Synodus variegatus	Variegated Lizardfish
		Trachinocephalus myops	Bluntnose Lizardfish
Gadiformes	Bregmacerotidae	*Bregmaceros mcclellandi*	Spotted Codlet
Batrachoidiformes	Batrachoididae	*Allenbatrachus grunniens*	Grunting Toadfish
		Austrobatrachus dussumieri	Flat Toadfish
Lophiiformes	Antennariidae	*Antennarius nummifer*	Spotfin Frogfish
Atheriniformes	Atherinidae	*Atherinomorus lacunosus*	Hardyhead Silverside
		Hypoatherina temminckii	Samoan Silverside
Beloniformes	Belonidae	*Ablennes hians*	Flat Needlefish
		Platybelone argalus platura	Keeltail Needlefish
		Strongylura leiura	Banded Needlefish

Order	Family	Genus and species	English name
		Strongylura strongylura	Spottail Needlefish
		Tylesurus crocodilus crocodilus	Hound Needlefish
	Exocoetidae	*Cypselurus oligolepis*	Largescale Flyingfish
		Parexocoetus mento	African Sailfin Flyingfish
	Hemiramphidae	*Hyporhamphus sindensis*	Sind Halfbeak
		Hemiramphus marginatus	Yellowlip Halfbeak
		Hyporhamphus quoyi	Quoy's Garfish
		Rhynchorhamphus georgii	Long-billed Halfbeak
Cyprinodontiformes	Cyprinodontidae	*Aphanius dispar*	Arabian Pupfish
Syngnathiformes	Syngnathidae	*Bryx analicarens*	Pink Pipefish
		Cosmocampus investigatoris	Investigator Pipefish
		Doryrhamphus excisus excisus	Bluestripe Pipefish
		Hippichthys penicillus	Beady Pipefish
		Hippocampus kuda	Spotted Seahorse
	Fistulariidae	*Fistularia petimba*	Red Cornetfish
	Centriscidae	*Centriscus scutatus*	Grooved Shrimpfish
Scorpaeniformes	Apistidae	*Apistus carinatus*	Ocellated Waspfish
	Synanceiidae	*Choridactylus multibarbus*	Orangebanded Stingfish
		Minous monodactylus	Grey Stingfish
		Pseudosynanceia melanostigma	Blackfin Stonefish
	Scorpaenidae	*Pterois miles*	Military Turkeyfish
		Pterois russellii	Plaintail Turkeyfish
		Scorpaenopsis barbatus	Bearded Scorpionfish
	Tetrarogidae	*Vespicula dracaene*	Draco Waspfish
Perciformes	Platycephalidae	*Platycephalus indicus*	Bartail Flathead
		Rogadius pristiger	Thorny Flathad
		Sorsogona tuberculatus	Tuberculated Flathead
		Thysanophrys celebicus	Sulawesi Flathead
	Serranidae	*Cephalopholis hemistiktos*	Yellowfin Hind
		Epinephelus areolatus	Areolate Grouper
		Epinephelus caeruleopunctatus	Whitespotted Grouper
		Epinephelus coioides	Orangespotted Grouper
		Epinephelus latifasciatus	Striped Grouper
		Epinephelus multinotatus	Whiteblotched Grouper
		Epinephelus polylepis	Smallscale Grouper
	Pseudochromidae	*Pseudochromis aldabraensis*	Orange Dottyback
		Pseudochromis persicus	Bluespotted Dottyback
	Priacanthidae	*Priacanthus tayenus*	Purple Spotted Bigeye
	Teraponidae	*Pelates quadrilineatus*	Fourlined Terapon
		Terapon jarbua	Jarbua Terapon
		Terapon puta	Smallscaled Terapon
		Terapon theraps	Largescaled Terapon
	Apogonidae	*Apogon coccineus*	Ruby Cardinalfish
		Apogon cyanosoma	Yellowstriped Cardinalfish
		Apogon fasciatus	Twostripe Cardinalfish
		Apogon nigripinnis	Bullseye
		Apogon taeniatus	Striped Cardinalfish
		Cheilodipterus persicus	Persian Cardinalfish
	Sillaginidae	*Sillago sihama*	Silver Sillago
	Lactariidae	*Lactarius lactarius*	False Trevally
	Rachycentridae	*Rachycentron canadum*	Cobia
	Echeneidae	*Echeneis naucrates*	Live Sharksucker
	Carangidae	*Alectis indicus*	Indian Threadfish

Order	Family	Genus and species	English name
		Alepes djedaba	Shrimp Scad
		Alepes kleinii	Sharpbelly Scad
		Alepes melanoptera	Blackfin Scad
		Alepes vari	Herring Scad
		Atropus atropos	Cleftbelly Trevally
		Atule mate	Yellowtail Scad
		Carangoides bajad	Orangespotted Trevally
		Carangoides caeruleopinnatus	Coastal Trevally
		Carangoides chrysophrys	Longnose Trevally
		Carangoides ferdau	Blue Trevally
		Carangoides fulvoguttatus	Yellowspotted Trevally
		Carangoides gymnostethus	Bludger
		Carangoides malabaricus	Malabar Trevally
		Carangoides praeustus	Brownback Trevally
		Caranx sexfasciatus	Bigeye Trevally
		Decapterus russelli	Indian Scad
		Gnathanodon speciosus	Golden Trevally
		Megalaspis cordyla	Torpedo Scad
		Naucrates ductor	Pilotfish
		Parastromateus niger	Black Pomfret
		Scomberoides commersonnianus	Talang Queenfish
		Scomberoides lysan	Doublespotted Queenfish
		Scomberoides tol	Needlescaled Queenfish
		Selar crumenophthalmus	Bigeye Scad
		Selaroides leptolepis	Yellowstripe Scad
		Seriola dumerili	Greater Amberjack
		Seriolina nigrofasciata	Blackbanded Trevally
		Trachinotus blochii	Snubnose Pompano
		Trachinotus mookalee	Indian Pompano
		Trachurus indicus	Arabian Scad
		Ulua mentalis	Longrakered Trevally
		Uraspis helvola	Whitetongue Jack
	Coryphaenidae	*Coryphaena hippurus*	Common Dolphinfish
	Menidae	*Mene maculata*	Moonfish
	Leiognathidae	*Leiognathus bindus*	Orangefin Ponyfish
		Leiognathus daura	Goldstripe Ponyfish
		Leiognathus decorus	Decorated Ponyfish
		Leiognathus equulus	Common Ponyfish
		Leiognathus fasciatus	Striped Ponyfish
		Leiognathus oblongus	Oblong Ponyfish
		Secutor insidiator	Pugnose Ponyfish
	Lutjanidae	*Lutjanus argentimaculatus*	Mangrove Red Snapper
		Lutjanus ehrenbergi	Ehrenberg's Snapper
		Lutjanus fulviflamma	Blackspot Snapper
		Lutjanus johnii	John's Snapper
		Lutjanus lutjanus	Bigeye Snapper
		Lutjanus malabaricus	Malabar Blood Snapper
		Lutjanus quinquelineatus	Fivelined Snapper
		Lutjanus russelli	Russell's Snapper
		Pinjalo pinjalo	Pinjalo
	Caesionidae	*Caesio lunaris*	Lunar Fusilier

Order	Family	Genus and species	English name
		Caesio varilineata	Variablelined Fusilier
	Lobotidae	*Lobotes surinamensis*	Tripletail
	Gerreidae	*Gerres acinaces*	Longtail Silver-biddy
		Gerres filamentosus	Whipfin Silver-biddy
		Gerres oyena	Common Silver-biddy
	Haemulidae	*Diagramma pictum*	Painted Sweetlips
		Plectorhinchus gaterinus	Blackspotted Rubberlip
		Plectorhinchus pictus	Trout Sweetlips
		Plectorhinchus sordidus	Sordid Sweetlip
		Pomadasys kaakan	Javelin Grunter
		Pomadasys maculatus	Saddle Grunt
		Pomadasys stridens	Striped Piggy
		Pomadasys taeniatus	Bronzestriped Grunter
	Sparidae	*Acanthopagrus berda*	Picnic Seabream
		Acanthopagrus bifasciatus	Twobar Seabream
		Acanthopagrus latus	Yellowfin Seabream
		Argyrops filamentosus	Soldierbream
		Argyrops spinifer	King Soldierbream
		Cheimerius nufar	Santer Seabream
		Crenidens crenidens	Karanteen Seabream
		Diplodus sargus kotschyi	Onespot Seabream
		Rhabdosargus haffara	Haffara Seabream
		Rhabdosargus sarba	Goldlined Seabream
		Sparidentex hasta	Sobaity Seabream
	Lethrinidae	*Lethrinus borbonicus*	Snubnose Emperor
		Lethrinus lentjan	Pinkear Emperor
		Lethrinus microdon	Smalltooth Emperor
		Lethrinus nebulosus	Spangled Emperor
	Nemipteridae	*Nemipterus bipunctatus*	Delagoa Threadfin Bream
		Nemipterus japonicus	Japanese Threadfin
		Nemipterus peronii	Notched Threadfin
		Scolopsis bimaculatus	Thumbprint Monocle
		Scolopsis frenatus	Bridled Monocle Bream
		Scolopsis ghanam	Arabian Monocle Bream
		Scolopsis taeniatus	Blackstreaked Monocle Bream
		Scolopsis vosmeri	Whitecheek Monocle Bream
	Polynemidae	*Eleutheronema tetradactylum*	Fourfinger Threadfin
		Polydactylus sextarius	Blackspot Threadfin
	Sciaenidae	*Johnius belangerii*	Belanger's Croaker
		Johnius borneensis	Sharpnose Hammer Croaker
		Johnius dussumieri	Sin Croaker
		Otolithes ruber	Tigertooth Croaker
		Pennahia anea	Bigeye Croaker
		Protonibea diacantha	Spotted Croaker
	Mullidae	*Mulloidichthys flavolineatus*	Yellowstripe Goatfish
		Parupeneus forsskali	Red Sea Goatfish
		Parupeneus heptacanthus	Cinnabar Goatfish
		Parupeneus margaritatus	Pearly Goatfish
		Upeneus asymmetricus	Asymmetrical Goatfish
		Upeneus doriae	Gilded Goatfish
		Upeneus tragula	Freckled Goatfish

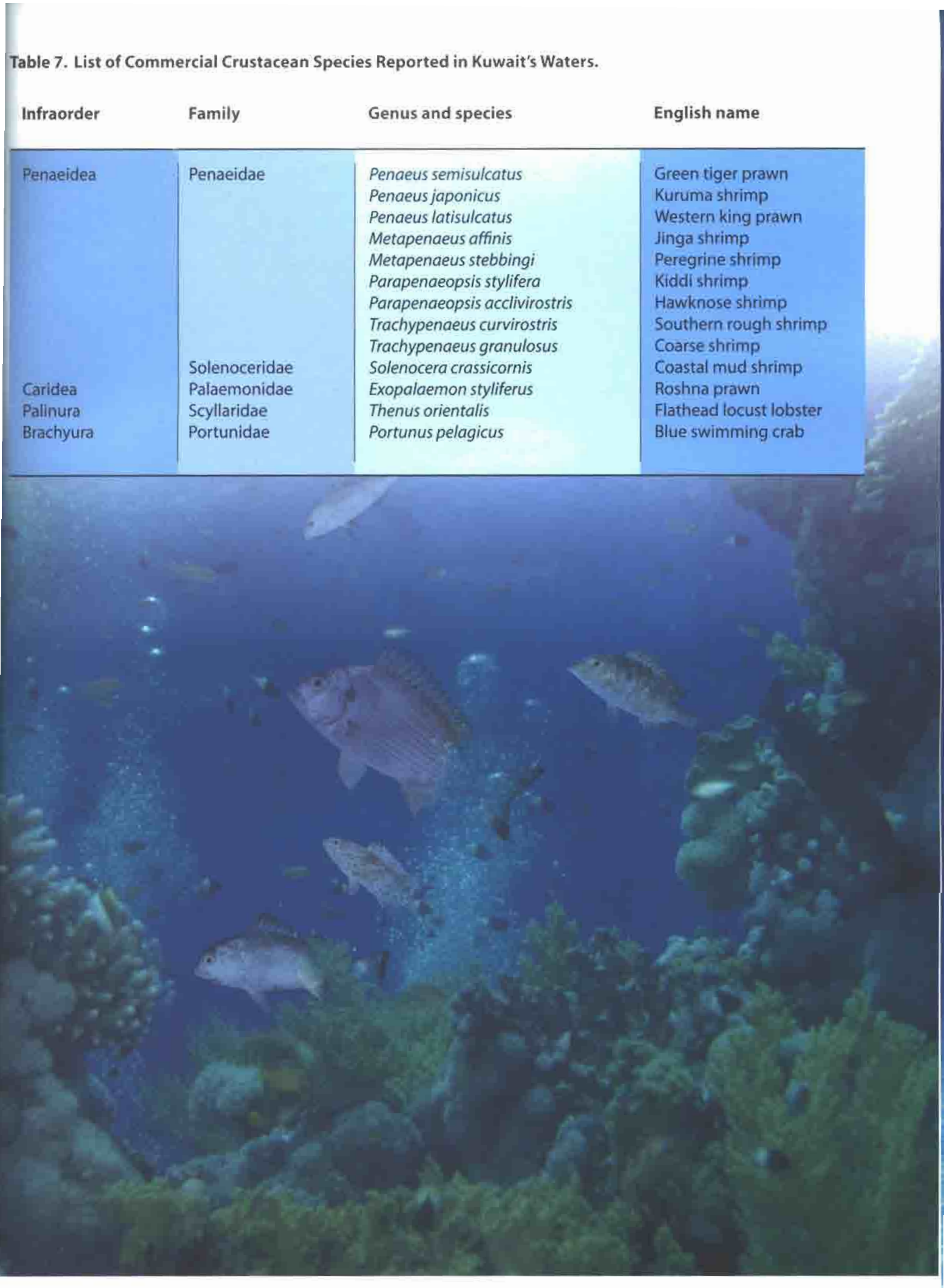
Order	Family	Genus and species	English name
		Upeneus vittatus	Striped Goatfish
	Drepanidae	*Drepane longimana*	Concertina Fish
		Drepane punctata	Spotted Sicklefish
	Chaetodontidae	*Chaetodon melapterus*	Arabian Butterflyfish
		Chaetodon nigropunctatus	Dark Butterflyfish
		Heniochus acuminatus	Longfin Bannerfish
	Pomacanthidae	*Pomacanthus maculosus*	Yellowbar Angelfish
	Pomacentridae	*Abudefduf vaigiensis*	Indo-Pacific Sargeant
		Chromis flavaxilla	Arabian Chromis
		Chromis xanthopterygia	Yellowfin Chromis
		Dascyllus trimaculatus	Threesot Dascyllus
		Neopomacentrus sindensis	Arabian Demoiselle
		Pomacentrus aquilus	Dark Damselfish
		Pomacentrus leptus	Slender Damselfish
		Pomacentrus trichourus	Paletail Damselfish
		Pristotis obtusirostris	Gulf Damselfish
	Labridae	*Halichoeres leptotaenia*	Thinstriped Wrasse
		Halichoeres marginatus	Dusky Wrasse
		Halichoeres stigmaticus	U-Spot Wrasse
		Halichoeres zeylonicus	Goldstripe Wrasse
		Labroides dimidiatus	Black-and-Blue Cleaner Wrasse
		Leptojulis cyanopleura	Shoulderspot Wrasse
		Paracheilinus mccoskeri	McCosker's Wrasse
		Stethojulis interrupta	Cutribbon Wrasse
		Suezichthys gracilis	Slender Wrasse
		Thalassoma lunare	Moon Wrasse
		Xyrichtys bimaculatus	Twospot Razorfish
	Scaridae	*Chlorurus sordidus*	Daisy Parrotfish
		Scarus ghobban	Bluebarred Parrotfish
		Scarus persicus	Gulf Parrotfish
	Mugilidae	*Liza abu*	Abu Mullet
		Liza klunzingeri	Klunzinger's Mullet
		Liza macrolepis	Largescale Mullet
		Liza subviridis	Greenback Mullet
		Liza vaigiensis	Squaretail Mullet
		Mugil cephalus	Flathead Mullet
		Valamugil seheli	Bluespot Mullet
	Opistognathidae	*Opistognathus nigromarginatus*	Bridled Jawfish
	Pinguipedidae	*Parapercis cylindrica*	Cylindrical Sandperch
		Parapercis nebulosa	Barfaced Sandsmelt
		Parapercis robinsoni	Smallscale Sandperch
	Tripterygiidae	*Enneapterygius ventermaculus*	Blotched Triplefin
	Blenniidae	*Antennablennius adenensis*	Aden Blenny
		Antennablennius variopunctatus	Orangedotted Blenny
		Escenius pulcher	Gulf Blenny
		Mimoblennius cirrosus	Fringed Blenny
		Omobranchus fasciolatus	Barred Arab Blenny
		Omobranchus punctatus	Muzzled Blenny
		Parablennius opercularis	Cheekspot Blenny
		Petroscirtes ancylodon	Arabian Fangblenny
		Petroscirtes variabilis	Variable Sabretooth Blenny

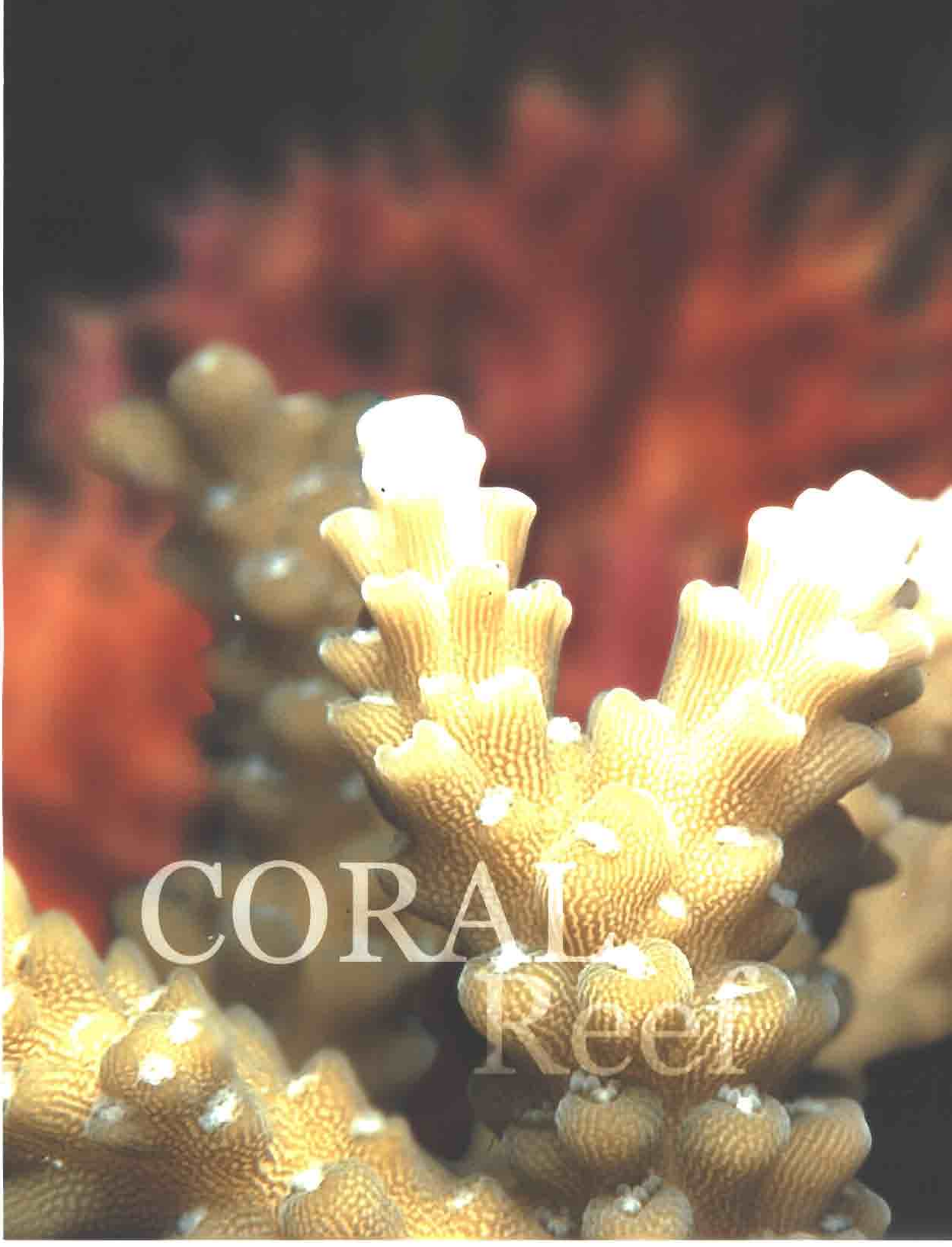
Order	Family	Genus and species	English name
	Callionymidae	*Callionymus erythraeus*	Smallhead Dragonet
		Callionymus filamentosus	Filamentous Dragonet
		Callionymus hindsii	Hind's Dragonet
	Gobiidae	*Acentrogobius cyanomos*	goby (no common name)
		Acentrogobius dayi	Day's Goby
		Amblyeleotris diagonalis	Slantbar Shrimpgoby
		Amblyeleotris downingi	Downing's Shrimpgoby
		Amblyeleotris periophthalma	Blotchy Shrimpgoby
		Amblygobius albimaculatus	Tailspot Goby
		Amblygobius nocturnus	Orangestriped Goby
		Apocryptodon madurensis	Minature Mudskipper
		Asterropteryx semipunctatus	Halfspotted Goby
		Bathygobius fuscus	Dusky Frillgoby
		Boleophthalmus boddarti	Boddart's Goggle-eyed Goby
		Boleophthalmus dussumieri	Dussumier's Mudskipper
		Coryogalops monospilus	Onespot Goby
		Cryptocentrus filifer	Gafftopsail Shrimpgoby
		Cryptocentrus lutheri	Luther's Prawngoby
		Eviota pardalota	Leopard Dwarfgoby
		Eviota sebreei	Redstripe Dwarfgoby
		Gnatholepis anjerensis	Anjer Goby
		Gobiodon reticulatus	Reticulated Coral Goby
		Gobiopsis canalis	Checkered Goby
		Istigobius decoratus	Decorated Goby
		Istigobius ornatus	Ornate Goby
		Oligolepis acutipennis	Sharptail Goby
		Parachaeturichthys polynema	Taileyed Goby
		Periophthalmus waltoni	Walton's Mudskipper
		Scartelaos tenuis	Indian Ocean Slender Mudskipper
		Trimma winterbottomi	Winterbottom's Goby
		Trypauchen vagina	Burrowing Goby
		Valenciennea persica	Gulf Goby
		Valenciennea sexguttata	Sixspot Goby
		Yongeichthys criniger	goby (no common name)
	Microdesmidae	*Ptereleotris arabica*	Arabian Dartfish
	Ephippidae	*Ephippus orbis*	Spadefish
		Platax teira	Teira
	Scatophagidae	*Scatophagus argus*	Spotted Scat
		Scatophagus tetracanthus	Scatty
	Acanthuridae	*Acanthurus sohal*	Sohal
		Zebrasoma xanthurum	Yellowtail Surgeonfish
	Siganidae	*Siganus canaliculatus*	White-spotted Spinefoot
		Siganus javus	Streaked Spinefoot
	Sphyraenidae	*Sphyraena barracuda*	Great Barracuda
		Sphyraena flavicauda	Yellowtail Barracuda
		Sphyraena fosteri	Bigeye Barracuda
		Sphyraena jello	Pickhandle Barracuda
		Sphyraena obtusata	Obtuse Barracuda
		Sphyraena putnamiae	Sawtooth Barracuda
		Sphyraena qenie	Blacktail Barracuda
	Trichiuridae	*Eupleurogrammus glossodon*	Longtooth Hairtail

Order	Family	Genus and species	English name
		Eupleurogrammus muticus	Smallhead Hairtail
		Trichiurus lepturus	Largehead Hairtail
	Scombridae	*Euthynnus affinis*	Kawakawa
		Rastrelliger kanagurta	Indian Mackerel
		Scomberomorus commerson	Narrowbarred Spanish Mackerel
		Scomberomorus guttatus	Indo-Pacific King Mackerel
		Thunnus albacares	Yellowfin Tuna
	Stromateidae	*Pampus argenteus*	Silver Pomfret
Pleuronectiformes	Psettodidae	*Psettodes erumei*	Indian Spiny Turbot
	Bothidae	*Arnoglossus aspilos*	Spotless Lefteye Flounder
		Bothus pantherinus	Leopard Flounder
	Paralichthyidae	*Pseudorhombus arsius*	Largetooth Flounder
		Pseudorhombus elevatus	Deep Flounder
		Pseudorhombus javanicus	Javan Flounder
		Pseudorhombus malayanus	Malayan Flounder
	Cynoglossidae	*Cynoglossus arel*	Largescale Tonguesole
		Cynoglossus carpentieri	Hooked Tonguesole
		Cynoglossus puncticeps	Speckled Tonguesole
		Paraplagusia bilineata	Doublelined Tonguesole
	Soleidae	*Aesopia cornuta*	Unicorn Sole
		Brachirus orientalis	Oriental Sole
		Pardachirus marmoratus	Finless Sole
		Solea elongata	Elongate Sole
		Synaptura commersonnii	Commonson's Sole
		Zebrias synapturoides	Indian Zebra Sole
Tetraodontiformes	Triacanthidae	*Pseudotriacanthus strigilifer*	Longspine Tripodfish
		Triacanthus biaculeatus	Shortnose Tripodfish
	Balistidae	*Abalistes stellatus*	Starry Triggerfish
		Rhinecanthus assasi	Picasso Triggerfish
		Sufflamen chrysopterus	Flagtail Triggerfish
	Monacanthidae	*Aluterus monoceros*	Unicorn Leatherjacket
		Paramonacanthus japonicus	Hairfinned Latherjacket
		Paramonacanthus otisensis	Dusky Leatherjacket
		Stephanolepis diaspros	Reticulated Leatherjacket
	Ostraciidae	*Ostracion cubicus*	Yellow Trunkfish
		Ostracion cyanurus	Bluetail Trunkfish
	Tetraodontidae	*Arothron stellatus*	Stellate Puffer
		Chelonodon patoca	Milkspotted Puffer
		Lagocephalus lunaris	Lunartail Puffer
		Lagocephalus sceleratus	Elongate Puffer
	Molidae	*Mola mola*	Ocean Sunfish
		Ranzania laevis	Slender Sunfish

Table 7. List of Commercial Crustacean Species Reported in Kuwait's Waters.

Infraorder	Family	Genus and species	English name
Penaeidea	Penaeidae	*Penaeus semisulcatus*	Green tiger prawn
		Penaeus japonicus	Kuruma shrimp
		Penaeus latisulcatus	Western king prawn
		Metapenaeus affinis	Jinga shrimp
		Metapenaeus stebbingi	Peregrine shrimp
		Parapenaeopsis stylifera	Kiddi shrimp
		Parapenaeopsis acclivirostris	Hawknose shrimp
		Trachypenaeus curvirostris	Southern rough shrimp
		Trachypenaeus granulosus	Coarse shrimp
	Solenoceridae	*Solenocera crassicornis*	Coastal mud shrimp
Caridea	Palaemonidae	*Exopalaemon styliferus*	Roshna prawn
Palinura	Scyllaridae	*Thenus orientalis*	Flathead locust lobster
Brachyura	Portunidae	*Portunus pelagicus*	Blue swimming crab




CORAL
Reef



CORAL REEF DISTRIBUTION

Coral reef systems are one of the most productive, complex and biologically diverse in the world. They also rank as one of the most visually beautiful ecosystems. Anyone seeing a well-developed coral reef for the first time is struck by the sheer variety of marine life, the extraordinary range of spectacular colors and shapes, and the complex interactions of reef organisms. The secret to coral reef productivity lies in the association of a plant (an alga) with the polyp of the coral animal. The alga, known as zooxanthellae, lives symbiotically within the coral polyps, and most reef-building corals are zooxanthellate. The benefits of this relationship for the algae are that they gain a stable environment, protection, access to sunlight and a ready source of nutrients from the polyp's metabolites. The coral benefits from the production of energy-rich compounds leaked from the zooxanthellae and the removal of waste products. Living together in this fashion, they form one of the most productive biological systems known.

Corals are the primary producers of calcium carbonate deposited in the reef system, which is fused by coralline algae, such as *Lithothamnion*. Coralline algae help stabilize the reef ecosystem by providing both food and shelter to many reef organisms. The encrusting red coralline algae constantly cement coral skeletons together by precipitating calcium carbonate (Barnes and Chalker, 1990). This reinforces the reef system against wave action and other destructive forces. Green algae are also present around the reef, and provide various habitats for a variety of organisms representing different phyla. Cryptofauna (cavity dwellers which play an important functional role in the reef ecosystem) and many invertebrates inhabit the reef substrata because reefs provide good shelter, and these groups are important elements in the ecosystem, as they represent a food source for some coral reef fish (McCain et al., 1984; Chabanet et al., 1997). Coral reefs have important roles in maintaining biological diversity, as well as for fishing, tourism and coastal protection.

Corals are comprised of three major groups: true corals, soft corals and fire corals. All are classified in the Phylum Cnidaria, Class Anthozoa. The true corals belong to the Order Scleractinia, and are classified into two groups: those that build reefs (hermatypic corals) and those that do not (ahermatypic corals). Soft corals belong to the Order Alcyonacea, and fire corals are in the Order Milleporina. True corals occur throughout the world's oceans, including sub-temperate regions. Coral communities and reefs, however, develop best in the tropics between latitudes 23.5° north and south of the equator. Kuwait's latitude is about 29° N, placing it over 500 km north of the typical coral reef zone.

Hermatypic corals form three general types of reefs. These include fringing reefs, barrier reefs and atolls. Fringing reefs develop along shorelines and are well developed in the Red Sea, East Africa and around some Indo-Pacific islands. Barrier reefs are also associated with land masses, but occur offshore with a lagoon between the reef and shore. The most famous barrier reef is the Great Barrier Reef located off Australia's east coast. Atoll reefs are most common in the Indo-Pacific, and initially formed around an island that subsequently sunk below the water's surface.

Factors Limiting Coral Reef Development

A wide range of abiotic and biotic factors can affect coral community distribution. Some of these environmental factors have been reported to induce stress responses in reef corals, and, in some cases, a bleaching response occurs (Hudson, 1981). Ideal conditions to encourage coral growth include clear water, temperatures averaging about 23 to 25 °C, and salinities of about 35 psu. Reefs develop best away from the coast because fresh water runoff and high turbidities are reduced. Other factors that influence coral growth and survival are ultraviolet radiation, oil pollutants, nutrient concentrations, oxygen concentration and a balanced ecosystem. This latter term relates to fish, particularly predators, associated with coral reefs.

Abiotic Factors.

Temperature. Coral reefs are usually located where water temperatures are fairly constant within a few degrees of 23 °C. If temperatures persist above upper tolerance limits, corals will expel their zooxanthellae, resulting in a process termed "bleaching." Bleaching refers to the loss of zooxanthellae or their pigmentation from the coral tissue. Bleached corals have a reduced ability to grow or reproduce, and energy expenditure may exceed energy intake (Gates, 1990). Ejection of the zooxanthellae is usually the first symptom of a sublethal disturbance effect that, if continued, may lead to death of the coral host (Jokiel and Coles, 1990; Glynn, 1993). Corals may recover their pigmentation or zooxanthellae by reproduction from the small pool of zooxanthellae that remains in the tissue during even extreme bleaching events (Tudhope, 1992). In Kuwait, water temperatures around the island reefs may reach 33.9 °C during the summer and can drop to 11.5 °C in the winter. This extreme seasonal difference of 22 °C make Kuwait's corals some of the most environmentally tolerant in the world and, thus, of particular scientific interest.

Salinity. Corals thrive best in salinities that do not deviate much from that of the open ocean, i.e., 36 psu. Salinities that are either too high or too low will affect the symbiotic zooxanthellae and, thus, affect the coral's metabolism (Muthiga and Szmant, 1987). In the Arabian Gulf, salinities may reach 50 psu, and consequently, become a limiting factor for coral species along the coasts of Abu Dhabi, Saudi Arabia and Bahrain (Coles and Jokiel, 1992). Salinity and temperature extremes and other factors combine to limit coral diversity in Kuwait's waters.

Sedimentation. Corals need light for the zooxanthellae algae to photosynthesize. Turbid water reduces photosynthesis, which, reduces biological productivity for the host corals. If sedimentation is heavy for prolonged periods, the effect will be suffocation. Coral polyps can protect themselves from direct sediment settling by ciliary currents, tissue expansion and mucus entanglement (Fisk, 1981; Stafford-Smith and Ormond, 1992). If a long period of sedimentation occurs, however, bacteria may invade the coral tissues, resulting in death in extreme situations (Brown et al., 1990; Jeffrey et al., 1992). Layers of sediment on the reef substratum also inhibit recruitment of coral larvae, which require a solid substratum upon which to settle and metamorphose. Sediment loads in strong tidal currents can abrade the newly settled larvae (coral juveniles) from the substratum (Rogers, 1983; Richmond and Hunter, 1990; Babcock and Davies, 1991).

Low Tides. There is a continuous struggle between upward growth of coral and low tides. Aerial exposure limits coral growth (Johannes et al., 1983; Fadlallah et al., 1995). Exposure to prolonged periods of low tide will cause the coral to die, especially at higher latitudes during periods of low temperature (Fadlallah et al., 1995). Corals protect themselves from exposure to air and dehydration by secreting mucus, which requires some of the corals' energy reserves. In Kuwait, extremely low tides during unusually cold weather resulted in the death of the uppermost corals at several of the islands in the early 1980s.

Currents. Currents provide an optimum physico-chemical environment for coral reef development. Currents bring nutrients, disperse larvae and carry away metabolites, and corals, as well as coral reefs, grow in a manner to maximize their exposure to currents. Coral development in high latitude sites is usually associated with water currents of tropical origin (Boland and Hamon, 1970). For example, the Houtman Abrolhos Islands are influenced by the south-flowing Leeuwin current off Australia's west coast (Crossland, 1984); corals along the East African coast are supported by the southerly Agulhas current (Riegl and Branch, 1995); and Lord Howe Island and the Solitary Islands are associated with the East Australia Current (Veron and Done, 1979; Harriott et al., 1994; Harrison et al., 1995). Coral reefs off Japan's Ryukyu Islands are influenced by the northward-flowing Kuroshio Current (Veron and Minchin, 1992).

Biotic Factors. The availability, settlement and mortality of coral larvae are major factors affecting coral distribution (Pearson, 1981; Dai, 1988; Tomascik, 1991). Predation on corals by the crown-of-thorns starfish (*Acanthaster planci*) may cause massive mortality to corals (Walbran et al., 1989; Harriott et al., 1995).

Competition. Competition for resources occurs among coral species as well as other reef organisms. For coral species, those with faster growth tend to overgrow other species (Pearson, 1981; Bothwell, 1984; Dai, 1988; Lang and Chornesky, 1990). Latitudinal limits of coral reef development may be determined by competition between corals and macroalgae. Studies in high latitude reefs show that macroalgae are favored in reef areas with high nutrient concentrations (Pearson, 1981; Coles, 1988; Kirkman, 1995). During low winter temperatures at high latitude sites, algae may overgrow corals, which depresses coral growth. (Crossland, 1981; Pearson, 1981; Johannes et al., 1983).

Coral Reproduction. Patterns of coral reproduction have been documented in many regions around the world (Harrison and Wallace, 1990; Richmond and Hunter, 1990). Most coral species are hermaphroditic, but others are gonochoric (separate sexes), and corals can reproduce sexually and asexually. Sexual reproduction usually occurs once a year (Harrison et al., 1984; Willis et al., 1985; Babcock et al., 1986). In the western Arabian Gulf, synchronous coral spawning has been documented on the coast of Saudi Arabia (Fadlallah, 1996) and in Kuwait (Harrison et al., 1997).

Recruitment. The rate of recruitment can be a measure of the success of coral reproduction. Recruitment by sexual and asexual reproduction is affected by biotic factors like predation and competition, and by abiotic factors, such as environmental changes and disturbance, and the availability of suitable settlement substrata. Predation on newly recruited larvae can limit coral reef development. Coral populations are highly dependent on sexual recruits for recovery after catastrophic disturbances, such as predation by the crown-of-thorns starfish (Shinn, 1976; Pearson, 1981; Endean and Cameron, 1990; Harriott et al., 1995; Tomascik et al., 1996).

Growth. Growth of corals can be shown in annual band couplets produced during the late summer and early autumn when water temperature is highest (Highsmith, 1979; Crossland, 1981). The growth rate declines with increased depth, presumably due to reduced availability of light. From the literature, it appears that the more delicate corals tend to be the faster-growing branching corals, and the stronger corals tend to have a slower growth rate (e.g., the brain corals, Faviidae). Consequently, growth rate has been used as a quantitative measure of stress due to a disturbance or other limiting factors (Pearson, 1981; Brown and Howard, 1985).

Physical Characteristics of Kuwait's Coral Reef Systems

Compared with Kuwait's northern waters, corals are more abundant in the country's southern waters (Fig. 120), where they take the form of platform or patch reefs, or fringing coral assemblages. All reefs occur in waters less than 15 m deep, and the greatest coral growth and diversity occur in depths of less than 10 m. The best

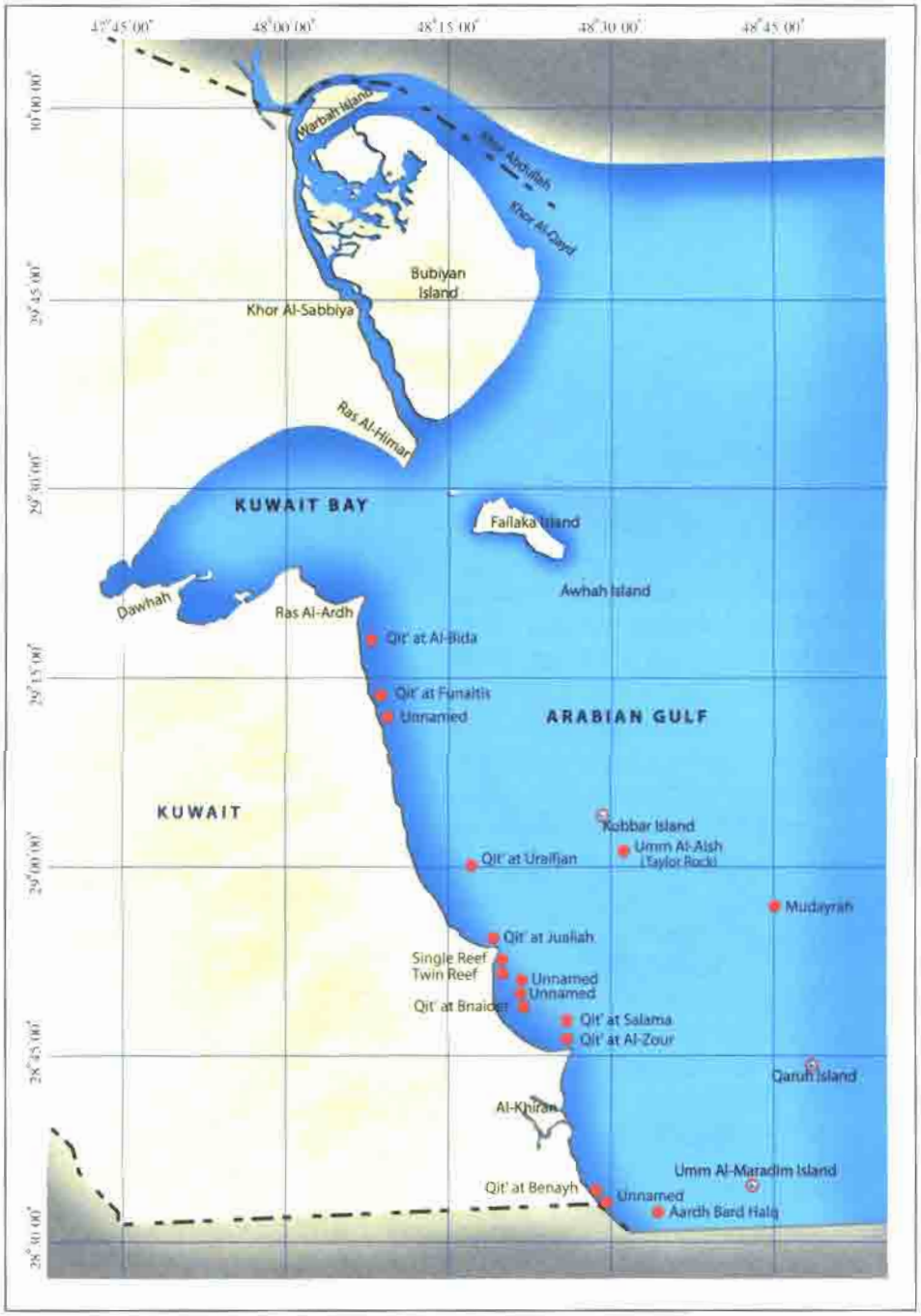


Fig. 120. Coral reefs of Kuwait.

developed coral reefs are those associated with the offshore islands of Kubbar, Qaruh and Umm Al-Maradim (Fig. 121). Kubbar is the northern most of the three coral islands (Fig. 121a). Roughly circular in shape and about 500 m in diameter, Kubbar Island is encircled by an extensive beach. The surrounding, elliptical-shaped reef is about 1300 m long and 900 m wide. Kubbar's reefal flat is dominated by *Porites* with reduced cover of *Acropora* and other coral species. Several small patch reefs with less cover and diversity of coral species are found to the north and northwest of Kubbar Island.

The largest and southernmost of Kuwait's coral islands is Umm Al-Maradim (Fig. 121b). Somewhat oval in shape, the island is about 550 m in length and is surrounded by sandy beach and beachrock. The surrounding reef is about 1100 m wide and 1400 m long and is dominated by massive stands of *Porites* corals, both living and dead, and small colonies of branching *Acropora* and *Stylophora*. Smaller patch reefs are located northwest and southeast of Umm Al-Maradim Island. Patch reefs to the northwest exhibit relatively high coral cover and diversity along the reef margins.

Qaruh is the smallest of the three coral islands, and is only 200 m in diameter (Fig. 121c). It is surrounded by an elliptical-shaped reef, with length and width dimensions of 1300 m and 600 m, respectively. Although the island is unvegetated, the reef of Qaruh Island is probably Kuwait's most diverse and visually attractive. The extensive reef flat is dominated by colonies of branching and table *Acropora* (Figs. 122a), some as large as 4 m in diameter, and massive stands of *Porites* (Fig. 122c). Other corals and reef organisms and diverse assemblages of fish occur down to depths of 15 m. Large *Porites lutea* colonies, estimated to be hundreds of years in age, dominate the reef slope. A small patch reef is located about 2 km northwest of Qaruh Island (Carpenter et al., 1997).



a.



b.



c.

Fig. 121. The three coral islands of a. Kubbar, b. Umm Al-Maradim and c. Qaruh (photos taken by Adel Al-Saffar).

There are other reefs not directly associated with the coral islands. These include no fewer than six inshore reefs and two offshore patch reefs, Mudayrah Reef and Umm Al-Aish. Mudayrah is the furthest offshore reef and probably experiences the most consistently clear water. The Mudayrah Reef community is diverse and includes a wide range of branching and encrusting corals (Carpenter et al., 1997). The Umm Al-Aish Reef, also known as Taylor Rock, is located about 10 km southeast of Kubbar. It is believed that the strong currents and small size are responsible for Umm Al-Aish's poor coral diversity. Inshore reefs experience increased sediment loads and higher turbidity, so development is more restricted than that of offshore reefs. Qit'at Uraifjan is perhaps the most important inshore reef. Located about 10 km southeast of the Shu'aibah Port, this reef is exposed to major pollution events, such as the discharge of oil during the Gulf War. The eastern reef slope consists of patches of living *Porites*, brain corals and other large corals that have obviously been present since before the Gulf War (Carpenter et al., 1997). South of Qit'at Uraifjan, several small patch reefs occur close to shore (Fig. 120). These include the following: Qit'at Julai'ah, Qit'at Bnaider, Qit'at Salama, Qit'at Benaya, Aardh Bard Halq, the reef near Ras Al-Zour, and others that are unnamed. Outcrops of corals occur in coastal areas as far north as Kuwait Bay, and some of these assemblages are comprised of surprisingly high numbers of species (Carpenter et al., 1997).



a.



b.



c.

Fig. 122. Different types of corals: a. ***Acropora*** *in the foreground (photo taken by Peter Harrison); b.* ***Acropora arabensis*** *(photo taken by Shaker Al-Hazeem); c.* ***Porites*** *(photo taken by Kent Carpenter).*

Species for Which Coral Reefs are Critical Habitats

Because Kuwait's coral reefs are so few in number and limited in extent, they are all critical habitats. These reefs have recently produced at least two species of fishes new to science, the Faintbar Shrimpgoby (*Amblyeleotris downingi*) and Winterbottom's Goby (*Trimma winterbottomi*), both described in 1994 (Randall et al., 1994). Additionally, a species of coral, *Acropora arabensis* (Fig. 122b), also new to science, was discovered on Kuwait's reefs (Hodgson and Carpenter, 1995). Many other species of fish and invertebrates, not to mention the corals themselves, would not be present in Kuwait's waters were it not for the presence of the reefs. Consequently, the reefs represent a concentration of species, and, considering their limited geographical extent, disproportionately contribute to Kuwait's biodiversity. Even with the intensive surveys that have been conducted on the reefs, most of the species living on the reef have not been identified, so there are likely many new distribution records and species new to science yet to be discovered. The reefs provide an essential habitat for parrotfish and other species that feed directly on the corals, and a significant habitat for commercial fish species such as hamoor and hamrah that, as juveniles and adults require rocky outcrops.



a.



b.



c.

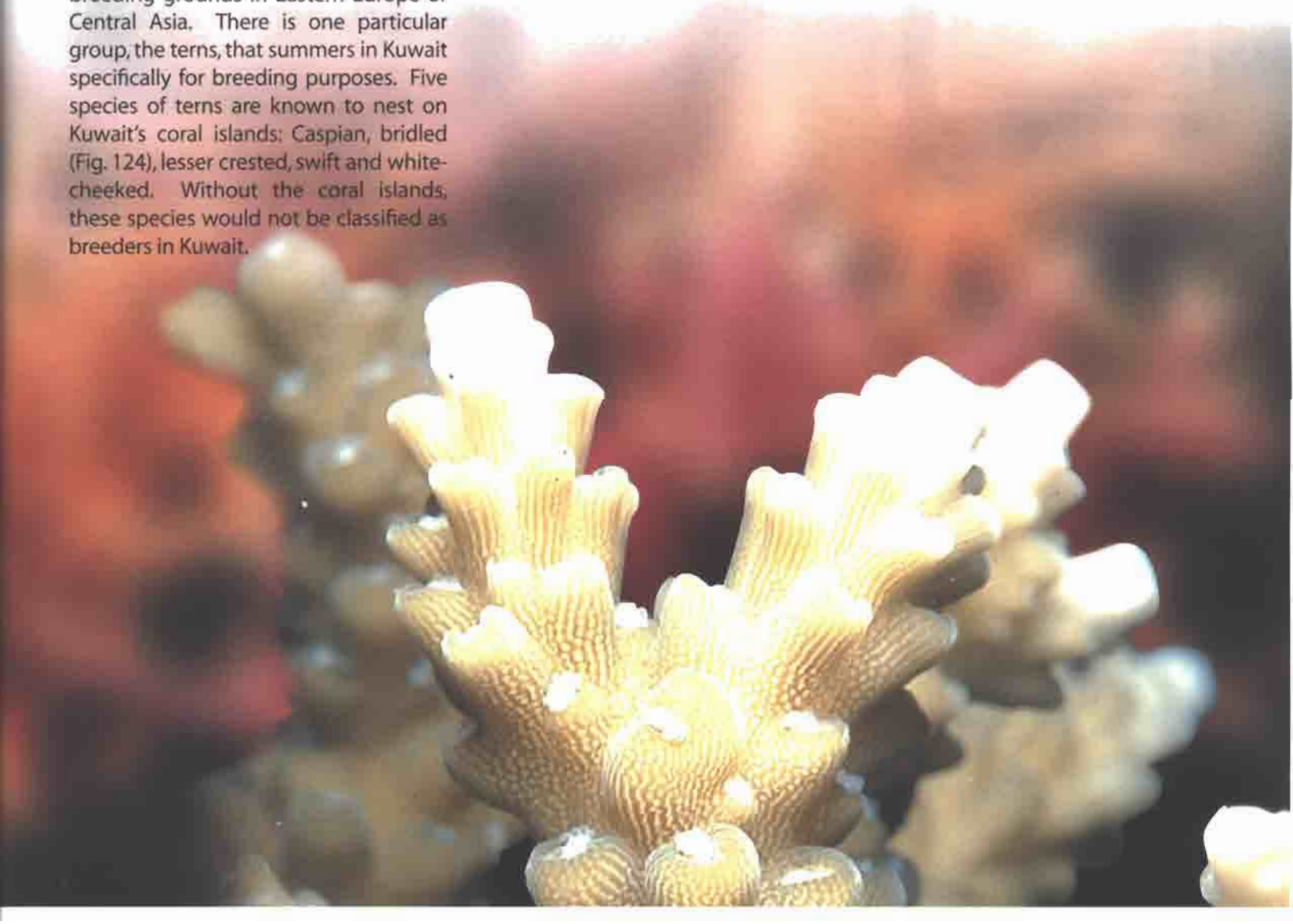
Fig. 123. Marine turtles in Kuwait's waters: a. green turtle on the beach (photo taken by Nigel Downing); b. Green turtle hatchling (photo taken by Nigel Downing); c. Loggerhead turtle (photo taken by Peter Harrison).

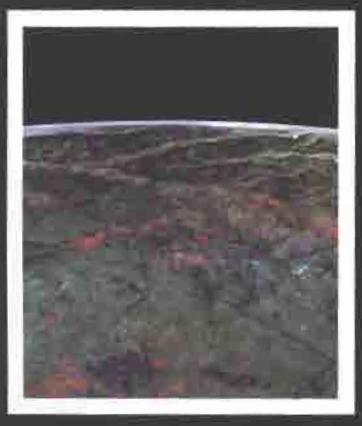
The coral islands serve as nesting habitats for two of Kuwait's three species of marine turtles. Hawksbill (*Eretmochelys imbricata*) and green (*Chelonia mydas*) turtles nest on the islands (Figs. 123a, 123b). Both these species are globally endangered, making the protection of breeding adults and their nesting habitat a high conservation priority. Nesting turtles are extremely important because they provide a biological barometer not available in any other species. Marine turtles are very long-lived and they exhibit high nesting fidelity, returning to the same nesting location for egg laying. By monitoring their nesting numbers and individuals (they can be easily tagged), fluctuations in turtle populations serve as one measure of environmental health. A third species, the loggerhead (*Caretta caretta*), occurs in Kuwait (Fig. 123c), but nesting has not been documented.

Most bird species in Kuwait are migratory and depart Kuwait for breeding grounds in Eastern Europe or Central Asia. There is one particular group, the terns, that summers in Kuwait specifically for breeding purposes. Five species of terns are known to nest on Kuwait's coral islands: Caspian, bridled (Fig. 124), lesser crested, swift and white-cheeked. Without the coral islands, these species would not be classified as breeders in Kuwait.



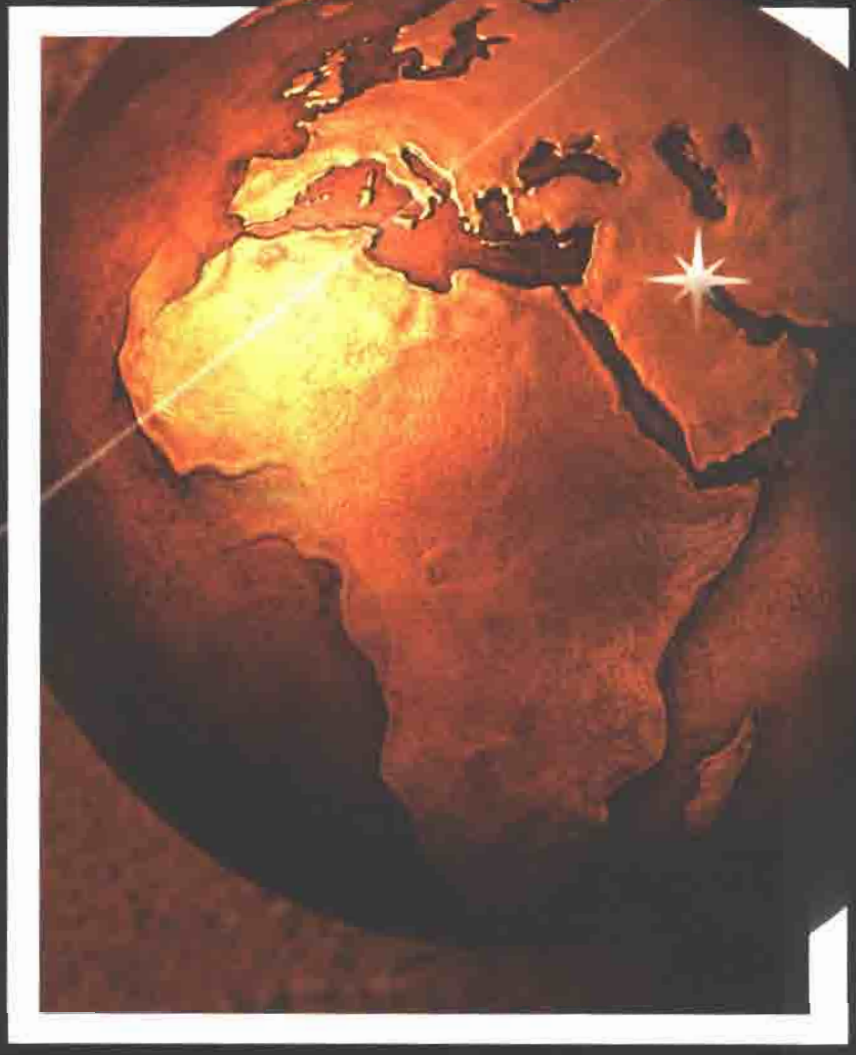
Fig. 124. Bridled tern (locally known as nawras) in Kubbar Island (photo by Adel Al-Saffar).











SATELLITE Oceanography OF KUWAIT

SATELLITE OCEANOGRAPHY OF KUWAIT

Remote sensing offers one of the most reliable means for long-term monitoring of Kuwait's marine environment. Quantitative and qualitative assessment of oceanographic variables, such as sea surface temperature, chlorophyll-*a*, suspended matter, vertical attenuation coefficients and color dissolved organic matter (CDOM)—also referred to as aquatic humus, yellow substances, Gelbstoff or gilvin—can be derived from remote sensing imagery. The combination of *in situ* measurements with remote sensing and ecosystem modelling greatly enhances our understanding of Kuwait's coastal ecosystem and its response to changes. Currently operating are several satellites with various spectral and spatial resolutions, as well as different re-visit times that are adequate to monitor Kuwait's marine environment on a continuous basis. Satellite image data of the Arabian Gulf areas have been recorded by various satellites since the early 1970s.

At present, satellites can provide regional views, such as the entire Arabian Peninsula (Fig. 125), or detailed images down to one-half meter resolution. In Fig. 125, which is a SeaWiFS satellite image, the Arabian Peninsula, one of the world's hottest and very dry regions, is surrounded by three major water bodies, namely, the Red Sea, the Arabian Sea, and the Arabian Gulf, which are shown in dark blue color. Kuwait Bay and surrounding areas in the NW corner of the Arabian Gulf are readily detected in the small-scale regional image.



Fig. 125. SeaWiFs satellite color composite image of the Arabian Peninsula, Red Sea, Arabian Sea and the Arabian Gulf recorded on 3 March 2000.

Sensors aboard satellites record reflected and emitted wavelengths in the visible, infrared and microwave regions of the electromagnetic spectrum. The biophysical information acquired by sensors can be directly or indirectly related to several variables, including the combination of the location, spectral characteristics, topography/ bathymetry, temperature and chlorophyll absorption characteristics. Depending on the wavelength and band combinations, different parameters in an area, which are usually shown in different colors, can be mapped from satellite imagery.

In Fig. 126, which is a moderate resolution imaging spectroradiometer (MODIS) satellite color composite image of the northern Arabian Gulf, the green and greenish-blue color represent shallow, turbid waters, whereas the dark blue (or black) depicts the Gulf's deeper, clearer waters. The marshlands in Iran are represented by the black "C- shaped" figure northeast of Kuwait.

The Landsat thematic mapper (TM), with a superior spatial resolution (30 m/pixel) to those of MODIS (250 m/pixel) and Sea-viewing Wide Field-of-view Sensor (SeaWiFS) (1.1 km/pixel) imagery, shows the northern Arabian Gulf in much more detail (Fig. 127). The red color in Fig. 127, which is a color composite of TM bands 1, 2 and 4, represents the distribution of chlorophyll in the Gulf and date-palm groves along the



Fig. 126. MODIS color composite image of the northern Arabian Gulf recorded on 28 May 2002.

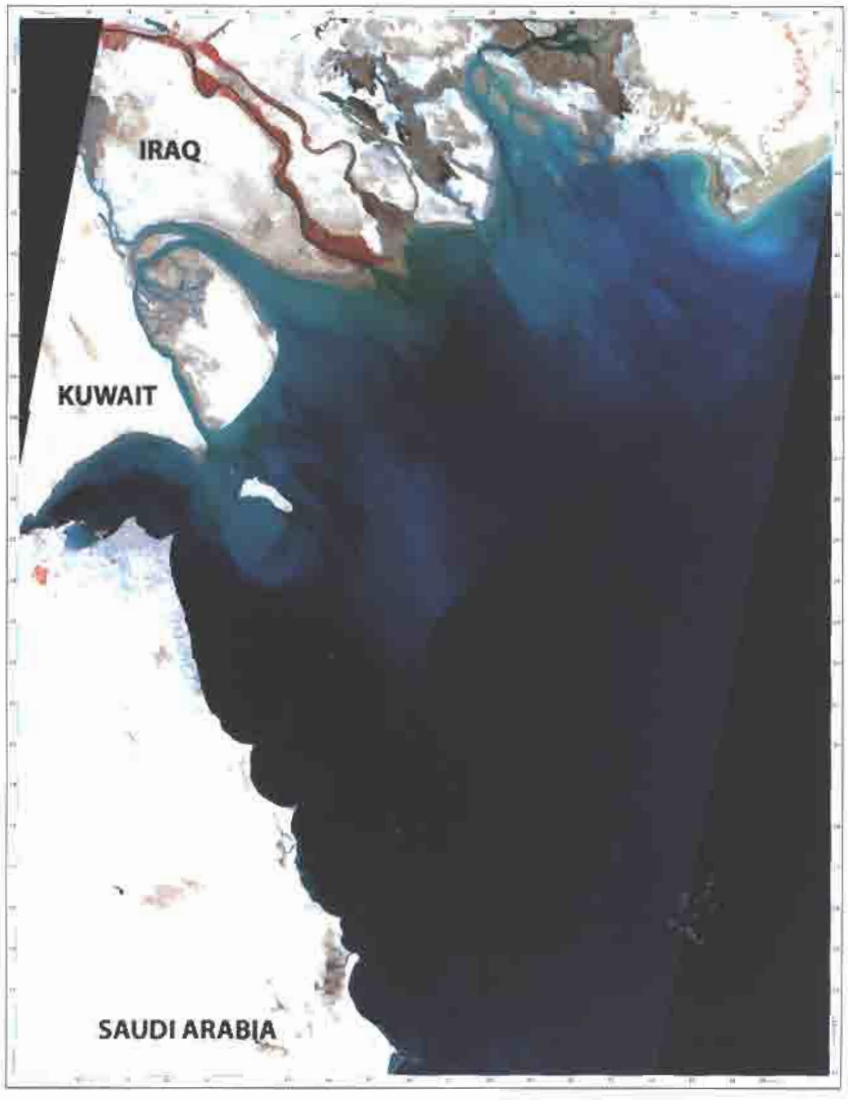


Fig. 127. Landsat thematic mapper color composite image using bands 1, 2, and 4 of northern Arabian Gulf acquired on 25 June 1989.

Shatt Al-Arab below the city of Basrah, Iraq. The small red spot south of Kuwait Bay shows the location of the large agricultural project off the Sixth Ring Road near Kuwait City. The shades of blue in the image denote variations in bathymetry, with dark blues representing deeper waters. Most of the Gulf is depicted as dark blue. In the very north of the Gulf, however, the watercolor ranges from green, yellowish-green, greenish-blue to lapis blue (Fig. 127). Shallow, turbid waters, such as those in north Kuwait Bay and around Bubiyan Island, show up as greenish blue. Shades of green-red color in the marine environment indicate the relative abundance of chlorophyll. Turbid, but deeper waters, such as those east of Falaika Island and off the Iranian coast, are lapis blue.

The TM bands 1, 2 and 4 color composite image of Kuwait Bay (Fig. 128) shows the shallower waters of Kuwait Bay and Sulaibikhat Bay in shades of green, and identifies some of Kuwait's most valuable remaining shrimp nursery habitat. The green color is absent in the immediate coast between Ras Ajouzah and Ras Al-Ardh, where the waterfront development projects have filled in almost all the intertidal zone. In winter, when this image was recorded, macrobenthic algae was a prominent feature of the intertidal areas along Shuwaikh Port and north of Dawhah Peninsula. The red color seen in these two areas represents the algae. Red flecks scattered throughout Kuwait City and east of Sulaibikhat Bay depict terrestrial vegetation (Fig. 128). The IKONOS satellite high resolution image of the eastern part of Sulaibikhat Bay and Dawhah Peninsula shows intertidal macrobenthic algae as shades of green (Fig. 129). Shades of blue represent bathymetry and turbidity, with the darker blues depicting the deeper waters. The red plume in the lower right-hand corner of Sulaibikhat Bay represents effluent from the Shuwaikh Industrial Area. The IKONOS satellite image with a resolution of one meter per pixel allows more detailed features to be mapped than the images from Landsat and MODIS. Figure 130 shows a Landsat TM bands 2, 4 and 7 color composite image of Bubiyan Island and the adjacent mainland. Shades of green color represent chlorophyll from vegetation, and light blue depicts areas with high soil-moisture content, i.e., sabkha. Dark blue represents water.



Fig. 128. Landsat thematic mapper color composite image using bands 1, 2, and 4 of Kuwait Bay recorded on 31 January 2001.

Sea surface temperature distribution derived from Landsat TM's thermal infrared band is presented in Fig. 131. The image shows that, on 25 June 1989, the Gulf's surface waters ranged from a low of about 25 °C near Ras Al-Ardh to a high of over 33 °C in Sulaibikhat Bay during the satellite's overpass at approximately 10:30 a.m. Besides Sulaibikhat Bay being very shallow, thus a large surface area to volume ratio allowing considerable incident radiation per unit volume of water, the cooling waters of the Dawhah East and West Power Stations are discharged into the Bay. These cooling waters are higher than ambient Bay temperatures. Most of the Gulf's surface temperatures varied from 27 to 30 °C.



Fig. 129. IKONOS satellite color-composite image of part of Sulaibikhat Bay and Dawhah Peninsula recorded on 19 February 2000.



Fig. 130. Landsat thematic mapper color composite image using bands 2, 4, and 7 of Bubiyan Island, Warbah Island and surrounding areas recorded on 30 March 1995.

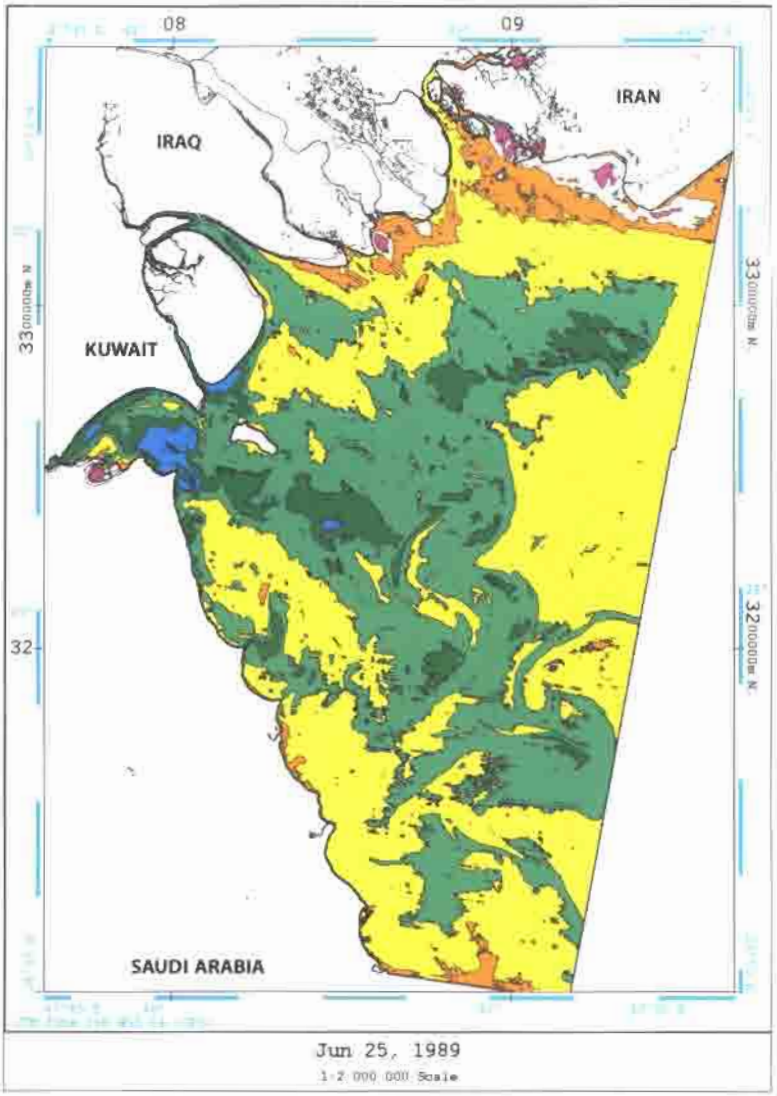


Fig. 131. Landsat thematic mapper derived sea surface temperatures of the northwestern Arabian Gulf recorded on 25 June 1989.

25.25 - 26.0 °C
28.25 - 29.0 °C
31.25 - 32.0 °C
26.25 - 27.0 °C
29.25 - 30.0 °C
32.25 - 33.0 °C
27.25 - 28.0 °C
30.25 - 31.0 °C
33.25 - 34.0 °C

The table below provides examples of coastal ocean-color application areas, requirements for spatial resolution and extent, temporal resolution, and examples of current or planned platforms and sensors meeting those requirements. (GLI= Global Imager; MERIS= Medium Resolution Imaging Spectrometer; MODIS= Moderate Resolution Imaging Spectroradiometer; NEMO= Naval EarthMap Observer; SeaWiFS= Sea-viewing Wide Field-of-view Sensor; SEI= Special Event Imager). Source: Davis, C.O., J.T.O. Kirk; J.S. Parslow; and S. Sathyendranath, 2000. Measurement requirement for case 2 waters. In: Remote Sensing of Ocean Color in Coastal, and Other Optically Complex Waters. IOCCG Report no. 3. Sathyendranath, S. (ed.) Canada.

Applications/Issues	Spatial Resolution x Extent	Temporal Resolution	Examples of Suitable Platforms/Sensors
River plumes outfalls	(30m -1Km) x (300m - 100Km)	Hours - weeks	GLI, MERIS, MODIS, NEMO, SeaWiFS
Tidal plumes, jets, frontal dynamics	(100m -1Km) x (1Km - 10Km)	Hours	Airborne, SEI
HAB, aquaculture, coastal water quality	(100m -1Km) x (1Km - 100Km)	Days - weeks	GLI, MERIS, MODIS, NEMO, SeaWiFS
Bathymetry and shallow benthic habitat: distribution, status	(1m -30m) x (1Km - 100Km)	Weeks - months	Airborne platforms, ARIES, NEMO
Maritime operations: navigation, visibilty	(30m -1Km) x (30Km - 100Km)	Hours - days	MERIS, MODIS, NEMO, SeaWiFS
Oil spills	(100m -1Km) x (1Km - 100Km)	Hours - days	Airborne, MERIS, MODIS, NEMO, SEI
Operational fisheries oceanography	1Km -1000Km	Days	GLI, MERIS, MODIS, SeaWiFS
Integrated regional management	(30m -300m) x (30Km - 300Km)	Days	MERIS, NEMO

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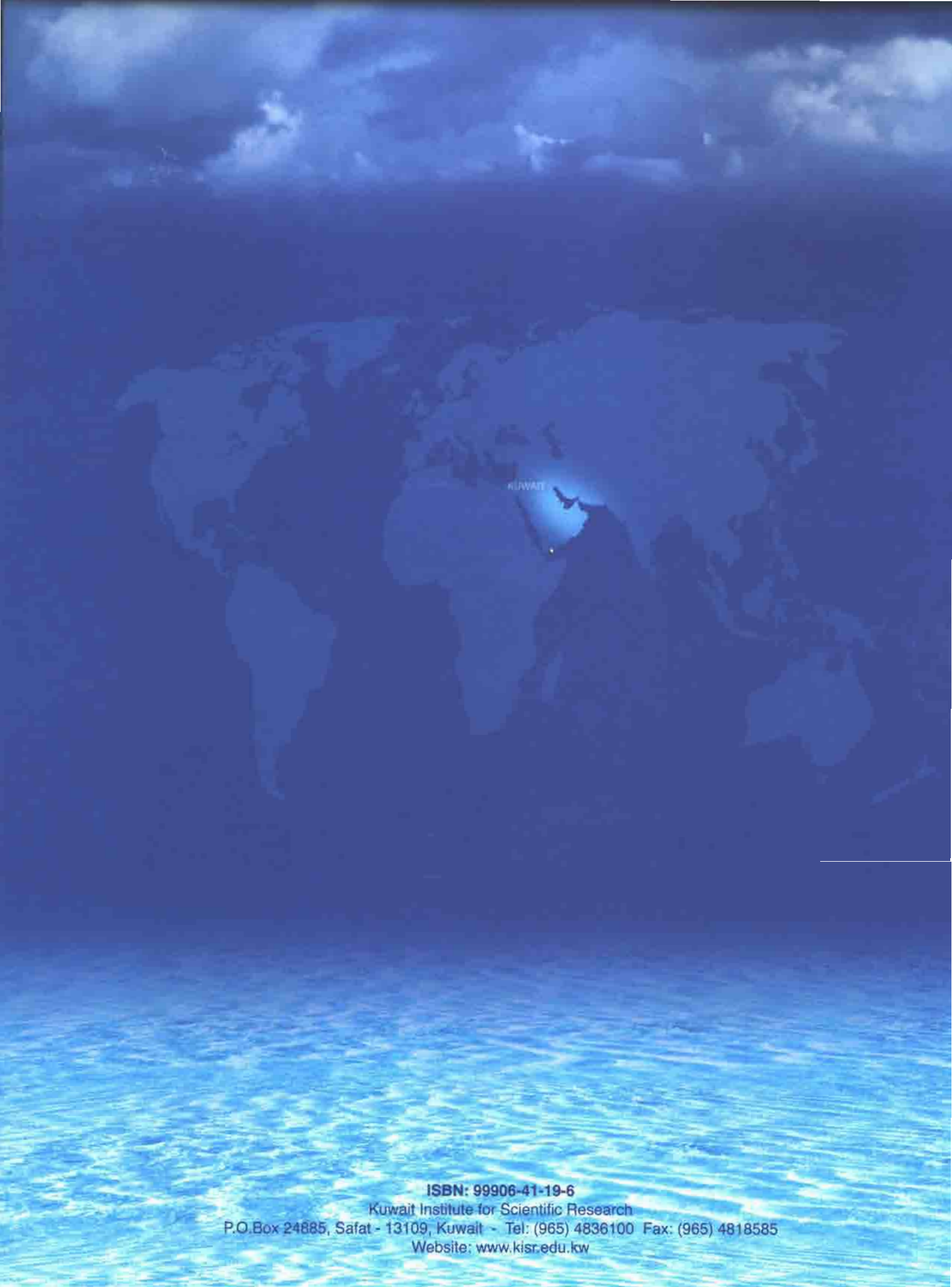
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